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Crop Yield and Economic Analyses of Selected Multiple Pivot Irrigation Schemes

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CROP YIELD AND ECONOMIC ANALYSES OF SELECTED MULTIPLE PIVOT IRRIGATION SCHEMES

by

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

Irrigation is becoming increasingly important in South Dakota agriculture. In recent years South Dakota land under irrigation permit has been increasing at a rate of from 14,000 to 24,000 hectares (35,000 to 60,000 acres) per year. In 1975 permits for an additional 48,000 hectares (119,000 acres) were granted (Department of Natural Resources Development 1975). An estimated 40 to 45 percent of the 88,000 hectares (217,000 acres) under irrigation is irrigated by means of sprinklers, and from two-thirds to three-fourths of the land irrigated by sprinklers is irrigated by means of center pivot irrigation machines (Kerr and Pahl 1976).

One management option for an irrigator with a center pivot machine is to use the machine on more than one pivot or field during the growing season. Under certain conditions, this practice is thought to be economically favorable by some South Dakota irrigators (DeBoer and Chu 1975) and by many researchers (Stegman and Bauer 1970, Stegman 1975, Korven and Wiens 1974, Moore and Allen 1973). It is believed that the returns from multiple field use of a center pivot machine exceed the returns from single field operation, or in other words, the decreases in annual costs, due mainly to a lower initial investment, exceed possible losses due to yield reduction. This supposition is also supported by Stewart et al. (1974), whose research indicates that maximum profit may occur at some yield which is below the maximum crop yield.

There are many factors which influence an optimum economic irrigation policy. Some of these factors include: soil water holding capacity, soil characteristics, climate, water supply, crop yield potential, availability of labor and irrigation system characteristics (Stegman 1975). Most center pivot systems are designed to irrigate satisfactorily under wide variations in the parameters listed above. Two main factors that make the center pivot irrigation machine (hereafter referred to as center pivot) adaptable for operation on more than one field are that most center pivots are capable of operating at a wide range of pumping rates and that many systems are designed to operate only one-third to one-half of the growing season when used on only one pivot (Stegman 1975). These factors indicate that using a center pivot on more than one field is a possible irrigation management plan and may be an optimum irrigation plan in certain cases.

An economic study of a management program where a center pivot is used on more than one field also involves many factors. One main advantage to such a program is that an irrigator is able to spread the initial investment over more land area and thus lower the investment per irrigated area. Some of the disadvantages may come from the possibility of decreased yields and from increased labor. The increased labor required to move the system to an adjacent field is estimated at one man-hour per tower (DeBoer and Chu 1974). Some researchers (Stegman 1975, Korven and Wiens 1974, Moore and Allen 1973) have investigated the economics of such a program under certain conditions, however, there is little quantitative information available on the yield response when such a program is used under South Dakota climatic conditions and also when used in connection with soils that have limited moisture storage.

There are presently some South Dakota irrigators using their center pivot irrigation machines on more than one field. The program or scheme is used in both eastern and western South Dakota and on top soil depths varying from shallow soils of approximately 45 cm (1.5 ft) to deep soils of more than 150 cm (5 ft). The crops that are commonly being grown under the multiple field management scheme in South Dakota are alfalfa, corn, beans and small grain.

A project connected with the South Dakota State University Agricultural Experiment Station was initiated in 1972 to evaluate alfalfa and corn yield response to a management scheme where a center pivot is used on more than one field. The project was to take place in the South Dakota climatic region and to include a limited soil moisture storage situation. In order to present the findings of the project and to evaluate the economics of such a scheme the following objectives of this study were established:

1. To develop production functions for corn and alfalfa that are applicable to South Dakota conditions and that can be used in irrigation economic analyses.
2. To make economic analyses of selected multiple field irrigation management schemes which utilize a center pivot irrigation machine on a shallow, droughty type soil.

LITERATURE REVIEW

An economic study of an irrigation management program involves many factors, which must be either measured or estimated in order for the study to be realistic. Some research which relates to the estimation of factors applicable to an economic study of the use of one center pivot machine on more than one field has been done. This research has generally fallen into the areas of evapotranspiration and crop yield, system capacities and simulation of multiple field irrigation.

Evapotranspiration and Crop Yield

The prediction of yield is an important factor in any economic study of an irrigation project. Many investigators have shown there is a relationship between evapotranspiration and yield (Stewart et al. 1975, Stewart et al. 1974, Downey 1972, Robins and Domingo 1953, Hillel and Guron 1973, Hanks 1974, Neghassi et al. 1973, Fischbach and Somerhalder 1972 and Stegman 1975). An estimate of evapotranspiration is fundamental to a prediction of yield in most of the relationships that have been developed. Jensen et al. (1971) have done considerable work on a computer program which estimates evapotranspiration and soil moisture depletion. Some of the inputs into the program were: daily maximum and minimum air temperature, daily solar radiation, average dew point temperature, daily wind run, rainfall, irrigation, drainage and crop criteria. The researchers believe the program gives an accurate estimate of evapotranspiration and that it is refined enough to schedule irrigations on a commercial basis.

Brosz and Wiersma (1970) developed a procedure for estimating evapotranspiration for corn and alfalfa grown in eastern South Dakota. The procedure is based on average climatic data for given areas and uses the Jensen and Haise (1963) approach. One of the purposes of their work was to provide a reference which could be used by an irrigator to help schedule irrigations. Soil moisture levels were measured at 16 irrigated farms and compared to soil moisture levels estimated by using the derived evapotranspiration values and a water balance technique. The estimated values agreed quite well with the measured values. Stegman and Ness (1974) compared a water balance technique using average climatic data, along with three other techniques to the evapotranspiration model developed by Jensen et al. (1970). One of the conclusions of their work was that, on a medium to fine textured soil, a procedure relying on average climatic data, such as Brosz and Wiersma's procedure, performed about as well as the more sophisticated techniques.

Some researchers have indicated that yields are not only related to total seasonal evapotranspiration but also to the timing of evapotranspiration deficits. Some crops, such as corn, are highly sensitive to the timing of moisture shortages and may not produce appreciable yield until some threshold value of evapotranspiration has been reached (Stewart et al. 1975, Stewart et al. 1974, Downey 1972). Other crops, such as alfalfa, have no apparent growth stage which is particularly sensitive to the timing of moisture stresses and an incremental yield will begin with an increment of evapotranspiration (Downey 1972, Stewart and Hogan 1969). Downey (1972) compiled considerable data on water use-yield relationships for several crops including corn. Downey also cited numerous articles related to evapotranspiration deficits at various stages of growth. He concluded that the manner in which yields are reduced is not a simple function of evapotranspiration. It depends on both the physiological stage at which the stress occurs and on the severity of the stress.

Hanks (1974) developed a yield estimate based on deficits at particular stages of growth. He assumed that the ratio of actual yield to potential yield is represented by the multiplication of all the individual growth stage ratios of actual transpiration to potential transpiration, each raised to a power. The non linear model was used to predict corn yields obtained by Hillel and Guron (1973) and it produced excellent agreement between predicted and actual results. The Hillel and Guron research, which took place in Israel, related corn yield to water use. In 1969 the experiment showed an increase in corn yield from 4.4 tons/hectare (64 bu/acre) to 10.8 tons/hectare (156 bu/acre) with an increase in evapotranspiration from 34.5 cm (13.6 in) to 48.6 cm (19.1 in). The ranges in the 1970 growing season were from 0.8 tons/hectare (12 bu/acre) to 8.5 tons/hectare (122 bu/acre) with an increase in evapotranspiration of from 32.6 cm (12.8 in) to 49.5 cm (19.5 in). The results also indicated that water use efficiency, defined as dry matter produced per unit of water used, increases with higher quantities of irrigation water.

Many researchers have found that the critical moisture stress period for corn production is during the pollination period (Stewart et al. 1975, Stewart et al. 1974, Downey 1972, Robins and Domingo 1953).

Stewart et al. (1975) proposed that evapotranspiration deficits reduce corn yields through two distinct mechanisms: a primary and seemingly inevitable effect of seasonal total evapotranspiration deficits and a secondary and additional yield reduction, probably due to timing effects, which may exceed the primary effect. Stewart et al. (1975) examined the secondary effects in an experiment in which they deliberately imposed evapotranspiration deficits at all combinations of the three main growth stages of corn and grain sorghum. The eight treatments ranged from no irrigation at all to irrigation during all three growth periods in amounts to insure maximum evapotranspiration. The researchers found that corn yield is not affected nearly as much by an evapotranspiration deficit in the pollination period when there has been a previous deficit as when there is no deficit prior to this period. They also found a moisture stress during pollination without a prior stress would result in a severe reduction in yield, and that a severe moisture stress could be tolerated in the grain filling period if there had been a prior conditioning to moisture stress. The results of this research agreed with an earlier paper (Stewart et al. 1974) where the following recommendations for corn were made: 1. If there is a mild seasonal evapotranspiration deficit (to 10 percent of the seasonal potential evapotranspiration) it is least detrimental if it takes place in the vegetative growth stage or, if it cannot be imparted there, it should take place in the latter part of the grain stage. 2. Moderate seasonal evapotranspiration deficits (10-25 percent) are best imposed on two growth stages one of which must be the vegetative growth stage.

3. Severe seasonal evapotranspiration deficits (25-50 percent) must be distributed through all three growth stages.

The relative importance of a moisture stress during a particular growth stage has been indicated, however, some of the management schemes under consideration in this research are such that an irrigator cannot always apply excess water during a critical stage. When a center pivot irrigation system is used on more than one field during the growing season, increases in the evapotranspiration deficit will probably be gradual, especially on the deeper soils. Although the stresses that were imparted by Stewart et al. (1975) were usually severe and were imposed only at specific stages of growth, the experiment did indicate that a gradual increase in evapotranspiration deficit will condition the corn to moisture stresses and may lead to an optimum yield for a given value of evapotranspiration.

Stewart et al. (1974) defined a normative yield versus evapotranspiration curve as the curve derived when all deficits have been optimally distributed. It is hypothesized that the relationship is approximately linear and that any differences in the slope should be due to varietal differences only (Stewart and Hagan 1973, Hillel and Guron 1973). Stewart et al. (1974) believe that a reasonable estimate of yield may be obtained by using the evapotranspiration-yield relationships provided the actual curve does not deviate significantly from the normative curve.

Actual yield-water use data have been gathered in several research projects. Stewart and Hagan (1969) developed production functions for alfalfa. They derived a dimensionless relationship in which yield is represented by percent of maximum yield and water use is represented by percent of the water use associated with the maximum yield. They found that their data when put on such a basis varied about a linear relationship. Neghassi, Heermann and Smika (1973) along with Hanks (1974) indicate that, at least for first order results, dry matter alfalfa yield is directly proportional to water use.

Stewart and Hagan (1973) developed functions to predict the effects of crop water deficits at Davis, California. Their corn production data agrees very well ($R^2 = 0.98$) with the linear prediction equation $Y = -3553 + 593\ ET$ where the units on ET are inches of evapotranspiration and the units on Y are lb/acre of grain at 15.5 percent moisture. One of the conclusions of the research was that a quantitative evaluation can be made of various irrigation policies before they are actually implemented.

In some of the research at Davis, California (Stewart et al. 1974) evapotranspiration deficits did not have as pronounced an effect on corn yield as other research had indicated. One possible reason for this is that the soil at Davis is a deep soil with a high moisture holding capacity from which a crop can withdraw moisture when rainfall and irrigation are lacking. The soil may also be the reason that their data exhibited the extremely high degree of correlation.

The yield of a crop is closely related to the evapotranspiration. Some of the irrigation schemes considered in the research may not be able to apply water in amounts that would insure that maximum evapotranspiration takes place. There are basically two approaches to predicting yield on the basis of evapotranspiration. The first is based on a non-linear approach relating growth stages and evapotranspiration deficits during the growth stages. The second approach is a linear one where it is hypothesized that if evapotranspiration deficits are optimally distributed the relation between yield and evapotranspiration can be represented by a simple linear function. The second approach was investigated in this study.

System Capacity Investigations

Several papers have been written on estimating the required capacities for center pivot irrigation machines. Stegman and Bauer (1970) developed a computer scheduling model that simulated the operation of a center pivot. It is especially suited to determine if a center pivot can be used to irrigate more than one tract of land. Their model requires input of a production function if an economic analysis is desired. Some of the other inputs for their model are: system capacity, soil criteria, evapotranspiration data and management criteria.

Stegman and Shah (1971) compared two methods of estimating the capacity needed for irrigation systems at Oakes, North Dakota. They compared an extreme value analysis, based on peak evapotranspiration rates and specified recurrence intervals for climatic conditions, to a simulation model like the one developed by Stegman and Bauer (1970). The simulation model used a water balance. The comparison was made using small grain, corn and alfalfa as crops and 37 years of climatological data. Some of the results of their work indicate that the extreme value method generally overestimates the required application rates. The extreme value method indicated that a net pumping rate of at least 0.63 cm/day (0.25 in/day) is needed in the Oakes area where there is a water holding capacity of 11.4 cm (4.5 in) in the root zone. The simulation model indicated that a 0.46 cm/day (0.18 in/day) net pumping rate would provide adequate irrigation capacity and also that two 64.8 hectare (160 acre) tracts could be adequately irrigated by one center pivot.

Heermann et al. (1974) also used a simulation method to arrive at irrigation design capacities for eastern Colorado. They used a modified Pennman equation and a water balance concept in their simulation model. The researchers investigated corn and assumed a maximum root zone of 1.2 m (4 ft) with a linear expansion of the root zone from 0.5 m (1.5 ft) to 1.2 m (4 ft) between June 20 and July 20. It is estimated that the depletion of available soil moisture can be kept below 50 percent with a net irrigation of 0.56 cm/day (0.22 in/day) where the soil water holding capacity in the 1.2 m (4 ft) root zone is 7.4 cm (3 in) and with a net irrigation of 0.36 cm/day (0.14 in/day) where the soil water holding capacity is 25.4 cm (10 in). The results of this work would again indicate that it may be feasible to use a center pivot irrigation on more than one field.

Fonken and Fischbach (1974) describe an irrigation policy called programmed soil moisture depletion, in which the available soil moisture is deliberately allowed to be depleted as the growing season progresses. This type of soil moisture depletion schedule is somewhat similar to the soil moisture situation that exists when a center pivot is used on more than one field. Under typical conditions, Fonken and Fischbach suggest three basic rules for utilizing programmed soil moisture depletion: 1. Have a full or nearly full moisture profile soon after planting. 2. Start irrigation when the soil moisture deficit is greater than the application depth plus 2.5 to 5 cm (1 to 2 in) of possible rainfall. 3. Allow the soil moisture deficit to increase to 60 to 80 percent of the available moisture late in the season. They believe the main benefits of their program are that a lower system capacity is needed, that rainfall is better utilized and that off-season irrigation capability may be used.

The programmed soil moisture depletion concept (Fonken and Fischbach 1974) was used at Mead, Nebraska in the two year study by Fischbach and Somerhalder (1972). The soil used in the study was a Sharpsburg silty clay loam with a total water holding capacity of about 26.7 cm (10.5 in). The irrigation system capacities considered in the experiment were 0.76 cm/day (0.30 in/day), 0.61 cm/day (0.24 in/day), 0.38 cm/day (0.15 in/day) and 0.25 cm/day (0.10 in/day). The capacities represented peak daily use for corn, three-fourths of the peak daily use, one-half of the peak daily use and one-third of the peak daily use.

Some of the significant results of the research indicated that a system capacity of 0.38 cm/day (0.15 in/day), or about one-half of the peak daily use, would be adequate to irrigate corn on a uniform soil with a normal root zone and a water holding capacity of 17.5 cm/m (2.1 in/ft). This capacity is very near the average daily use of 0.35 cm (0.14 in) for corn at Redfield, South Dakota (Erie et al. 1954). It is feasible that a center pivot used on two fields would have a capacity approximately equal to this rate. Fischbach (1975) reported that a minimum system capacity of 0.61 cm/day (0.24 in/day) was needed during the drought year of 1974. Fischbach and Somerhalder (1972) also reported that irrigation frequencies of from 1.5 to 7 days per irrigation did not affect the yields. These results indicate that, except in extremely dry growing seasons, a center pivot irrigation machine used on more than one field may provide adequate water for corn grown in a normal root zone.

Multiple Field Irrigation

Much of the investigation concerning water use and yield prediction has been of a general nature and simulated a wide variety of management programs, however, some researchers have evaluated the particular management scheme of using a center pivot system on more than one field. Moore and Allen (1973) examined the feasibility of moving a center pivot irrigation machine on pasture lands in southern Alberta, Canada. The management schemes considered in the study were one center pivot irrigating three fields and two center pivots irrigating five fields. The cropping arrangements considered were all fields planted to grass or one field of corn silage and the rest planted to grass. The researchers estimated the time a particular irrigation machine would spend on a field and the production of the field. Using these estimates the researchers compared the economics, for a given amount of production, of using a center pivot on more than one field to the purchase of additional dryland. The research indicated that irrigated land was a reasonable economic alternative to dryland and would become more attractive as land values increased.

Other Canadian researchers, Korven and Wiens (1974), evaluated a management scheme where the system capacity was less than the peak water requirements of the crop. The plot study was conducted with alfalfa, bromegrass and wheat, which were grown in a uniform 1.4 m (4.5 ft) root zone. The basic treatment was designed to provide water equal to the crop use at a 14-day irrigation frequency. The reduction in capacity, simulating the use of a center pivot on more than one field, was achieved by changing the frequency of the 7.6 cm (3 in) application depth from 14 days per irrigation to 21 and 28 days per irrigation. The researchers found that the plant population on the non-irrigated forage plots decreased markedly through the years of the experiment and that the differences in yields between the irrigated treatments varied from year to year. They also found that the frequency of application has more influence on yield than the timeliness of application. One of the conclusions of the research was that the total yield of alfalfa, brome and wheat is not significantly decreased except in extremely dry years when the capacity of the system is only two-thirds of the peak water requirements. The economic study indicated that the profits, based on estimated annual costs and returns, would be maximized by using one center pivot on more than one field when the cost of land, water and management is low and that profits would be maximized by using a system on only one field when the cost of land, water and management is high.

DeBoer and Chu (1975) conducted a field evaluation of using a center pivot machine on more than one field. Several South Dakota irrigators, who were already using their center pivot machine on more than one field, participated in the study. By the nature of the study there was a wide range of variables presented. Each cooperator used one machine to irrigate from two to four fields ranging in size from 11 hectares (27 acres) to 32.4 hectares (80 acres). The storage capacity in the root zones ranged from 8.4 cm (3.3 in) to 19.3 cm (7.6 in) and the number of system moves during the growing season ranged from 2 to 16 times. Three of the conclusions made in the study were: 1. That shallow soils with limited water holding capacities could be adequately irrigated when a system is used on more than one field provided the system capacity is greater than peak crop requirements and labor is available for moving the machines. 2. That a seasonal two move, alfalfa to corn to alfalfa, management scheme is a viable option for moving center pivot machines. 3. That good management is necessary to avoid yield depression.

Some of the work that most closely parallels the work done in this research is that of Stegman (1975). Stegman conducted a field study where he simulated selected management schemes by means of plots. He used the data collected from the plots in an economic analysis of the schemes. The management schemes that Stegman simulated were one center pivot used on one, two and three fields, respectively. Crops used in the experiment were wheat, oats, alfalfa, corn, pinto beans and potatoes. The experiment simulated 53.4 hectare (132 acre) fields. Irrigation system capacities of 1.2, 0.61 and 0.41 cm/day (0.48, 0.24 and 0.16 in/day) were used to simulate the respective management schemes. The crops were grown in a Heimdal loam soil with an available moisture of

14.2 cm (6.5 in) in the 1.2 m (4 ft) root zone. The results of the research indicated that there were no significant differences in any of the irrigation treatments for any of the four years of the experiment. However, there was a difference in varietal response to irrigation. The data indicate that for all four years a 4.54 m^3/min (1200 gpm) well could have successfully irrigated three 53.4 hectare (132 acre) tracts of land even though three out of the four years were drought years.

Since there were no significant differences among the crop yields that could be attained, all of the irrigation schemes had approximately the same gross return, the gross return being the market value of the harvested crop. The return to land and management consisted of the gross return minus the annual fixed and operating costs of irrigation. Stegman indicated that the differences in operating costs between the various schemes were small. Thus, the main differences in net returns between the various irrigation schemes would then be the differences in fixed costs. In mid-1974 the fixed costs were estimated at \$126.10, \$74.80 and \$60.14/ hectare (\$51.03, \$30.27 and \$24.34/acre) for the management schemes of one center pivot used on one, two and three fields, respectively. At these costs there would be an economic gain of \$51.30/ hectare (\$20.76/acre) by using one center pivot on two fields instead of one, \$65.96/hectare (\$26.69/acre) by using one center pivot on three fields instead of one and \$14.66/hectare (\$5.93/acre) by using one center pivot on three fields rather than two. The research also showed that the economic gain could be reduced by poor management.

Research has been conducted which indicated that using a center pivot machine on more than one field may be economically feasible; however, to analyze the problem, some form of yield estimate is necessary. There have been numerous attempts at providing accurate estimates of yield, most of which have been related to climatic conditions, moisture conditions and soil properties. Many of these attempts have been estimates for crops grown under general management schemes. At the present time, however, there is limited information available to estimate the yields of crops grown in the South Dakota climatic region, especially under a multiple field management scheme used on shallow soil conditions.

RESEARCH PROCEDURE

The objectives of this research involve deriving a production function from which yield estimates can be made and then using the yield estimates as a part of an economic study. The economic study involves evaluating the returns of selected management schemes associated with different levels of irrigation equipment investment. In order to derive a production function, yield data had to be obtained. The yield data were gathered by means of a plot study simulating actual field management. Before making such a simulation, a problem analysis which would partially serve as a basis for both the plot simulation and the economic study was conducted.

Problem Analysis

Several assumptions were made so that the problem could be analyzed in a meaningful manner. One assumption was that the center pivot irrigation machine was towable from both ends. Machines which are towable from only one end and are capable of irrigating while going in either direction will deviate slightly from the assumption in the fact that they will have to make one and one-half revolutions per irrigation. The results from this research, however, will probably still be applicable. Based on research by DeBoer and Chu (1974), the time required to move a center pivot was estimated at one man-hour per tower which means, with sufficient man-power, a system can be moved to an adjacent field in about 0.25 days. Standard quarter section center pivot systems were considered in this study with an irrigated area of

52.6 hectares (130 acres) per field.

An assumption as to the pumping rate on a quarter section of land was determined, in part, by the South Dakota Water Law, section 46-5-6 (1972). The law states that the maximum irrigation rate is 1.0 m^3/sec/1000 hectares (1.0 cfs/70 acres). This law sets a legal limit on the pumping rate of about 3.0 m^3/min (800 gpm) for a single field. A double field pumping rate of 6.0 m^3/min (1600 gpm) would legally be possible, however, a pumping rate of 3.8 m^3/min (1000 gpm) was chosen as a realistic pumping limit for typical systems and wells in South Dakota.

Another basic assumption was that a typical gross application depth would be about 3.0 cm (1.2 in) and the application efficiency would be about 83 percent, which yields a net application of 2.5 cm (1 in) per revolution. Under the assumed pumping rate, application depth and field size, it would take 3.6 days per revolution for single field operation and 5.8 days for one revolution on each of two fields for dual field operation, Table 1.

Table 1. Time Allotments for the Completion of One Complete Irrigation Cycle Under the Given Assumptions.

Single field operation	Dual field operation
Q = 3.0 m^3/min (800 gpm)	Q = 3.8 m^3/min (1000 gpm)
3.0 cm gross application	3.0 cm gross application
2.5 cm net application	2.5 cm net application
52.6 hectare (130 acre) fields	52.6 hectare (130 acre) fields
3.6 days/revolution	5.8 days/2 revolutions
0.4 days downtime	0.5 days for 2 moves
	0.7 days downtime
4.0 days/cycle	7.0 days/cycle

The time allotments indicated in Table 1 also show an additional 0.4 days per cycle for single field operation and 0.7 days per cycle for dual field operation as downtime when the system would be inoperable due to repairs or other reasons. A cycle is defined as the amount of time required for the irrigation machine to return to a specified area in a given field.

With the assumed pumping rates and field size there are estimated maximum application rates of 2.5 cm/hr (1 in/hr) for single field operation of a center pivot and 3.2 cm/hr (1.25 in/hr) for dual field operation of a center pivot. The maximum application rates occur near the outer edge of the fields and are estimated by the equation

$$h = (122.5\ Q)/(Rr) \qquad \text{(Pair et al. 1973)}$$

where

h = maximum application rate, in/hr

Q = system capacity, gal/min

R = radius of center pivot, ft

r = wetted radius of end sprinkler, ft (assumed to be 75 ft)

The basic system arrangement considered in this research was the situation where there is one well, pump and irrigation machine used to irrigate the land under consideration. In the case of one center pivot being used on two fields the well is assumed to be between the two fields with buried mainline connecting the two pivots. Where one center pivot is used on one field the well is assumed to be adjacent to the pivot. The physical situations under consideration are indicated in Figure 1.

In order to complete the economic analysis associated with the second objective, cost information for equipment, electrical services and commodities had to be gathered. This information was obtained from irrigation equipment suppliers, power utilities and the South Dakota State University Extension Service. The data that were obtained are listed in Appendix A and are used as a basis for determining both the annual fixed and operating costs. Although current cost and price information was used, the absolute values will probably be accurate for a limited time into the future.

Field Procedure

The main purpose of the field experiment was to collect field data from which the yields from certain management schemes could be estimated. The management schemes that were under consideration are listed in Table 2. Treatments 1 through 4 represent single field operation. Treatments 5 through 8 represent dual field operation.

A completely randomized design with four replications was used in the experiment. The treatment-plot assignments remained the same during the three years of the experiment. Although there were six actual treatments per crop, there were only 4 basic management schemes. The first scheme was a dryland management scheme. The second scheme was one where a center pivot could apply 2.5 cm (1 in) to one 52.6 hectare (130 acre) field every four days. The third basic scheme was one where a center pivot could apply 2.5 cm (1 in) to a particular 52.6 hectare (130 acre) field every 7.0 days. This scheme simulates the situation

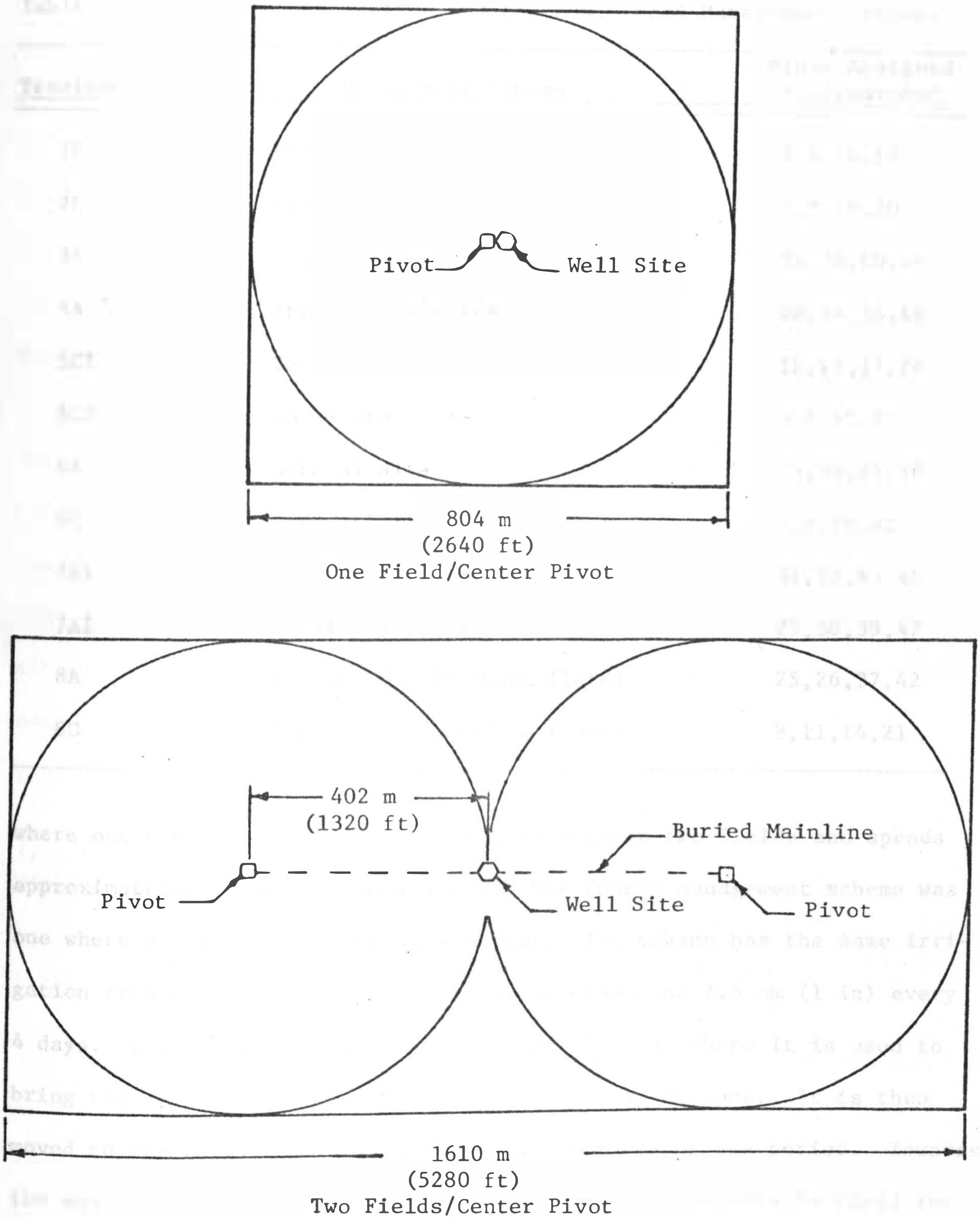

Figure 1. Proposed Layout of Irrigation Systems.

Table 2. Treatment Designation and the Associated Management Scheme.

Treatment	Management Scheme	Plots Assigned to Treatment
1C	Dryland Corn	2,4,16,18
2C	Irrigated Corn	7,9,10,20
3A	Dryland Alfalfa	29,36,40,44
4A	Irrigated Alfalfa	28,34,35,48
5C1	Corn-Corn	12,13,17,24
5C2	Corn-Corn	3,6,15,23
6A	Corn-Alfalfa	33,38,41,46
6C	Corn-Alfalfa	1,5,19,22
7A1	Alfalfa-Alfalfa	31,32,43,45
7A2	Alfalfa-Alfalfa	27,30,39,47
8A	Alfalfa (early)-Corn (late)	25,26,37,42
8C	Alfalfa (early)-Corn (late)	8,11,14,21

where one center pivot machine is shared between two fields and spends approximately 3.5 days on each field. The fourth management scheme was one where a system is moved twice a year. The scheme has the same irrigation frequency as the second management scheme or 2.5 cm (1 in) every 4 days. The machine begins the season on alfalfa, where it is used to bring the soil to near field capacity by the end of June. It is then moved to the corn field during the corn's high water use period. Towards the end of September the machine is moved back to the alfalfa field for either fall irrigation or preparation for spring irrigation. This management scheme will be called alfalfa (early)-corn (late).

The treatments designated 1C through 4A represent the first two management schemes. Treatments 5C1, 5C2, 6A, 6C, 7A1 and 7A2 all represent the third management scheme. Treatments 5C1 and 5C2 represent two corn fields that share a common center pivot machine. Both fields receive the same frequency and irrigation depth of 2.5 cm (1 in) every 7 days, however, the irrigations on each field are staggered by 3.5 days.

The treatments were meant to represent the actual irrigation of two fields where a center pivot begins irrigation on one field and then 3.5 days later it has completed a revolution, been moved and is ready to start irrigation on the second field. The treatments were also designed to bring out possible differences in yield due to timing effects of irrigation during critical crop moisture stress stages. The concept is illustrated in Figure 2.

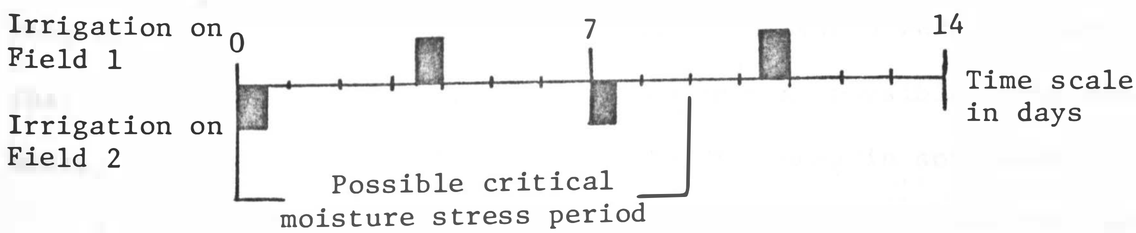

Figure 2. Illustration of Possible Irrigation Timing Effects.

Treatments 6A-6C and 7A1-7A2 represent the same types of management schemes as presented above only the crops grown in the fields sharing the common center pivot are alfalfa and corn in 6A-6C and alfalfa and alfalfa in treatments 7A1-7A2. Treatments 8A and 8C represent the alfalfa (early)-corn (late) management scheme described earlier.

The field experimental site was located 13 km (8 mi) southwest of Brookings, South Dakota at the South Dakota State University Agricultural Engineering Research Farm. Eighty-three years of climatological data for the research area were available from the Agricultural Engineering Department at South Dakota State University. The available data indicate an average of 127 days between the last frost in the spring and the first frost in the fall. The data also indicate an average rainfall of 37 cm (14.5 in) from May through September at the research area.

The general plot location on the Farm is indicated in Figure 3. The topsoil at the research farm is shallow and underlain by sand and gravel. Kramer (1972) sampled the soil in the plot area and determined the depth of the topsoil as well as other soil parameters. Figure 4 shows the variation in the depth of topsoil in the plot area. The average depth was approximately 46 cm (18 in) with the soil type ranging from a loam to a silty clay loam. The plots were arranged so that the depth of topsoil would be as uniform as possible, thus minimizing any extraneous variation due to differences in soil depth.

A second criteria used to locate the alfalfa plots was the vigor of the alfalfa stand. Again the plots were arranged so as to minimize any extraneous variation due to differences in the stand. The alfalfa was planted in 1971 and cropped for one year before the research began in 1973. Yield data from the corn and alfalfa plots were collected in 1973, 1974 and 1975.

The 46 cm (18 in) soil profile has a field capacity of approximately

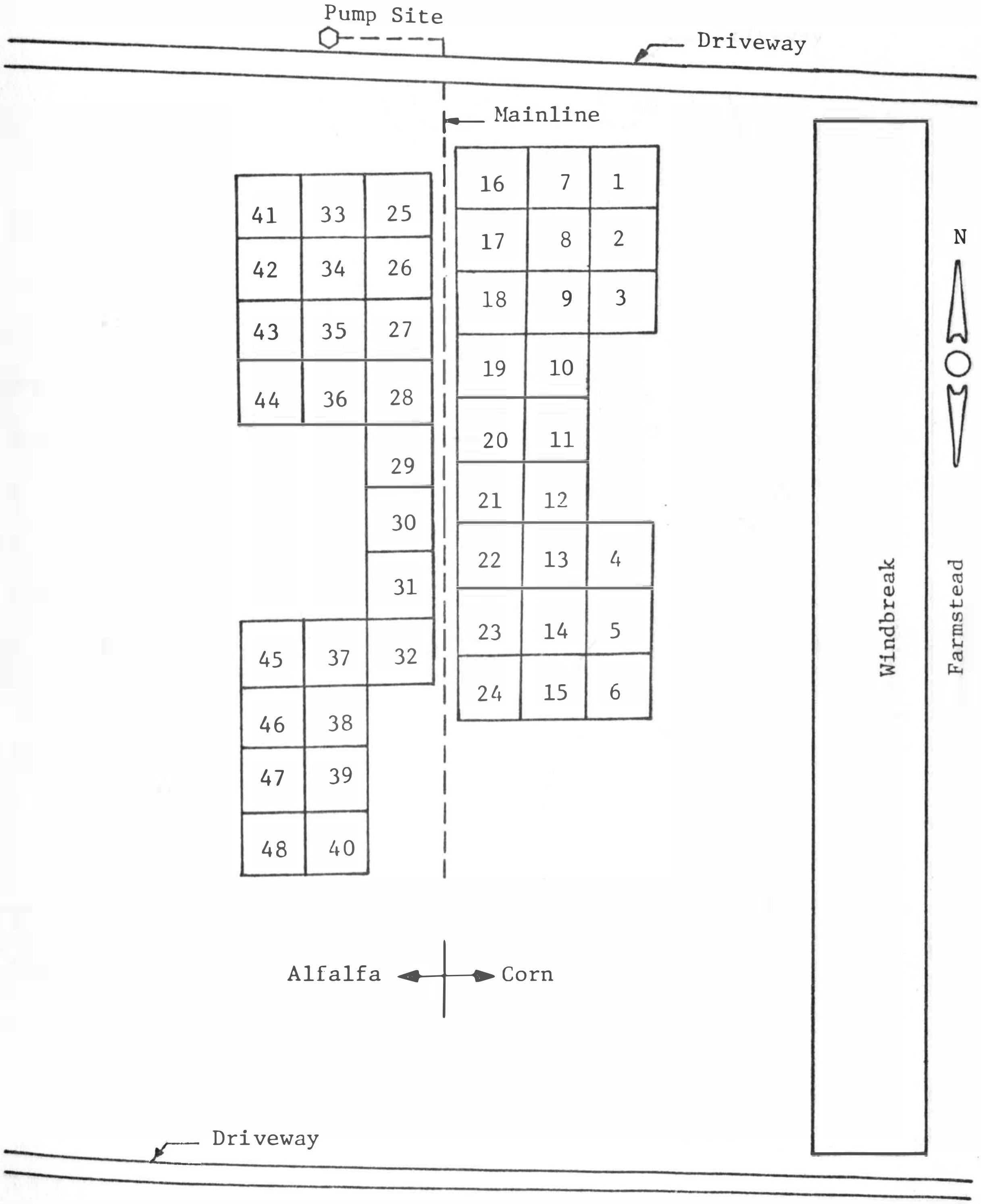

Figure 3. Plot Layout with Plots Identified by Number at the Agricultural Engineering Farm Near Brookings, South Dakota.

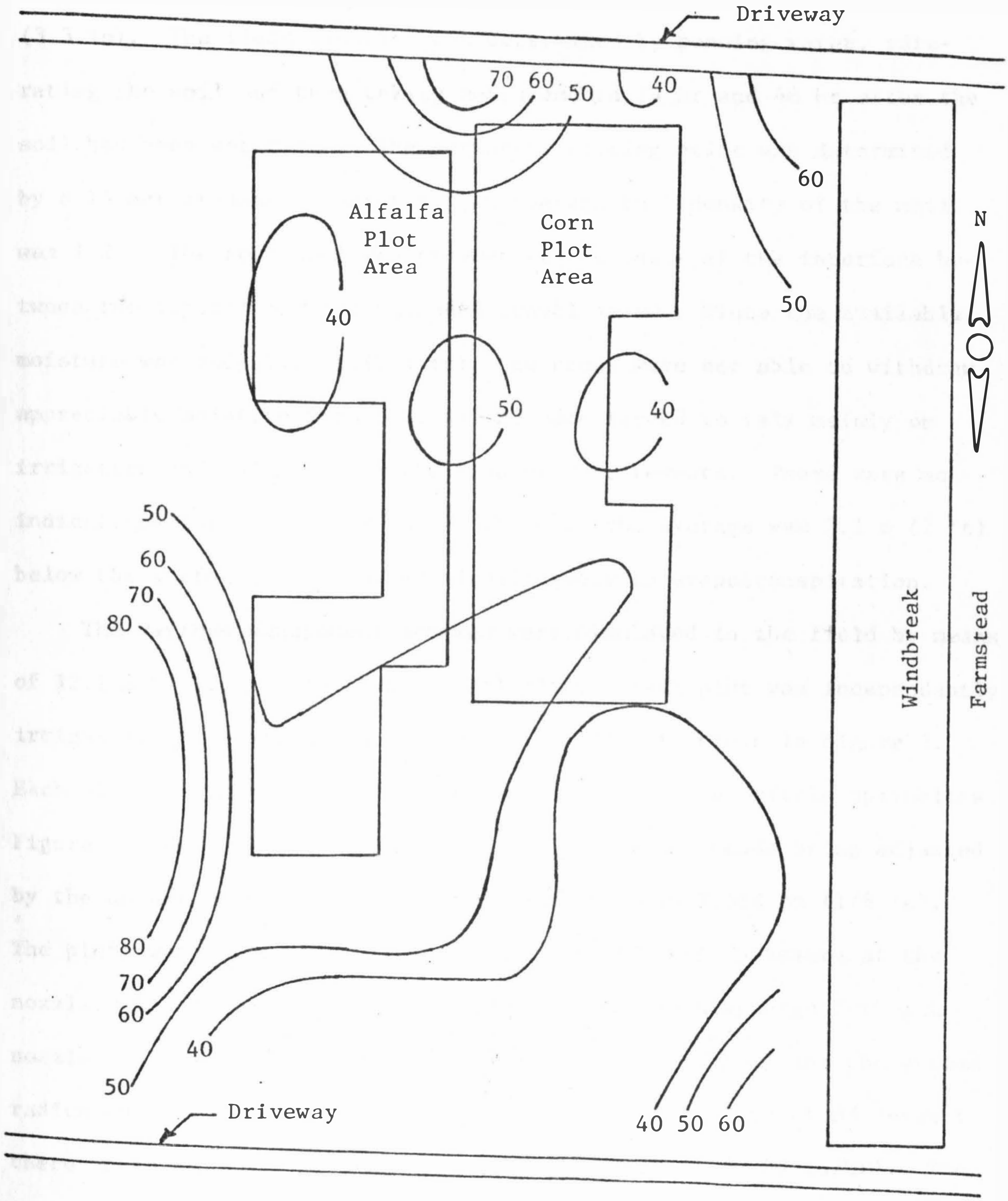

Figure 4. Depth of the Topsoil in the Plot Area at the Agricultural Engineering Farm Near Brookings. (Depth in cm)

14.5 cm (5.7 in) and a permanent wilting point of approximately 8.4 cm (3.3 in). The field capacity was determined by ponding water, saturating the soil and then taking measurements 24 hr and 48 hr after the soil had been saturated. The permanent wilting point was determined by a 15 bar pressure apparatus. An average bulk density of the soil was 1.33. The root zone was assumed to terminate at the interface between the topsoil and the sand and gravel below. Since the available moisture was only 6.1 cm (2.4 in), the crops were not able to withdraw appreciable moisture from storage and were forced to rely mainly on irrigation and rainfall for their water requirements. There were no indications that the water table, which on the average was 2.1 m (7 ft) below the surface, contributed significantly to evapotranspiration.

The various management schemes were simulated in the field by means of 12.2 m by 12.2 m (40 ft by 40 ft) plots. Each plot was independently irrigated. A detail drawing of a typical plot is shown in Figure 5. Each plot was irrigated by four Rainbird PJ25 quarter circle sprinklers. Figure 6 shows one of the quarter circle sprinkler heads being adjusted by the author. The sprinkler nozzle diameter was 0.318 cm (1/8 in). The plots were irrigated with about 5.8 Kpa (40 psi) pressure at the nozzle. According to Rainbird specifications the discharge for each nozzle, at the given pressure, was 0.0113 m^3/min (3 gpm) and the wetted radius was 11.3 m (37 ft). At an application efficiency of 83 percent there would be a net application rate of 1.52 cm/hr (0.60 in/hr). The experimental application depth of 2.5 cm (1 in) took 100 minutes to apply. The actual experimental application depths were occasionally

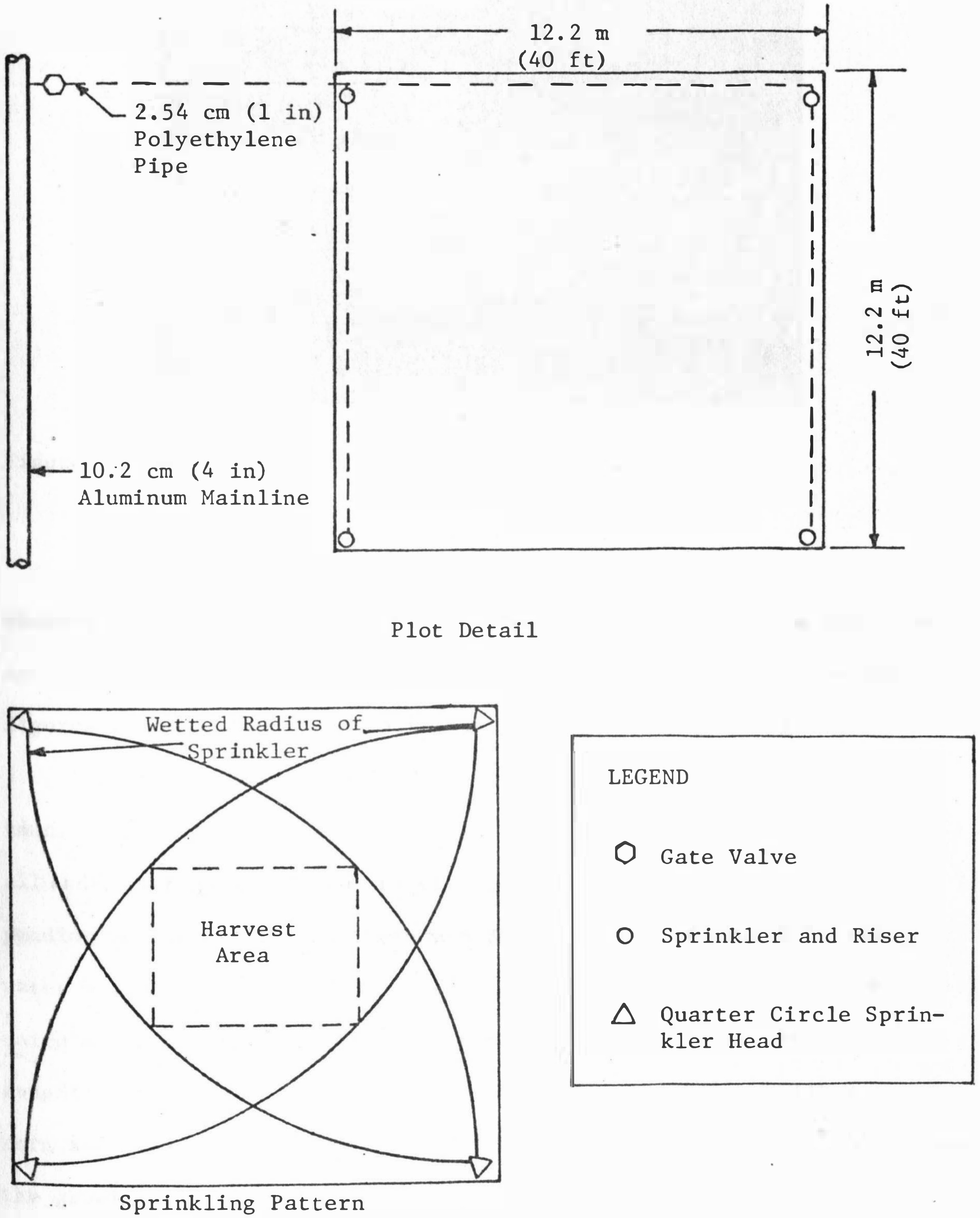

Figure 5. Typical Layout of Plot Sprinkling System.

Figure 6. Adjustment of a Quarter Circle Sprinkler Head.

checked in the field by placing measurement equipment in the plot area. Actual depths did not vary significantly from the calculated depths. Figures 7 and 8 show the alfalfa and corn plots being irrigated.

The irrigation scheduling aspect of this research was very important. Scheduling was based primarily on moisture depletion and the allowable irrigation frequency of 2.5 cm (1 in) every 4 or 7 days depending on the treatment. Moisture depletion was estimated by using a water balance and the method presented by Brosz and Wiersma (1970) to calculate evapotranspiration. This method estimates the potential evapotranspiration in the Brookings area to be about 46 cm (18.2 in) for corn and 67.5 cm (26.6 in) for alfalfa while the average rainfall during the growing season is 37 cm (14.5 in). Although the average amount of rainfall is fairly close to the potential evapotranspiration for corn

Figure 7. Alfalfa Plots Being Irrigated.

Figure 8. Corn Plots Being Irrigated.

it is an average value. The timing and depths of the individual rainfalls are such that crops generally cannot use the total depth in evapotranspiration, thus irrigation is usually needed for the crops to approach their potential evapotranspiration. This is especially true on shallow soils with low moisture holding capacities, such as the soil at the Agricultural Engineering Research Farm.

One of the basic objectives of the scheduling was to keep the available soil moisture depletion less than 50 percent, if possible. The shallow soil situation, however, presented particular scheduling problems. Since the experimental application depth was just less than one-half of the available moisture, the plots were generally irrigated as soon as the depletion approached the application depth and the frequency criteria would allow the application. Little or no allowance was usually made for rainfall storage.

The plots were sampled for moisture content periodically throughout the growing season by means of a moisture probe. The moisture content was measured on a gravimetric basis and then converted to a volumetric basis.

Throughout the growing season it became obvious that the Brosz-Wiersma method of estimating evapotranspiration would not accurately represent the moisture loss when the profile became dry. Since the soil moisture in the shallow soil at the plot area occasionally approached or dropped below the permanent wilting point, a moisture depletion factor similar to that used by Jensen et al. (1971) was applied. It was assumed that the actual evapotranspiration equaled the evapotranspiration predicted by the Brosz-Wiersma method times a factor Ka. The factor Ka equaled ln(RM+1)/ln(101), where RM is the percentage of remaining soil moisture that can be depleted. The factor was applied in calculating monthly and seasonal evapotranspiration and in calculating the moisture depletion curves shown in Appendix B. The factor was not used in the actual scheduling procedure. Scheduling irrigations by the Brosz-Wiersma method without the moisture depletion factor resulted in a slight increase in the seasonal irrigation over what would have been if the factor had been used.

The agronomic aspects of the experiment were conducted to simulate the management that an irrigator wishing to attain maximum yields would use. A summary of pertinent agronomic data is given in Table 3. The fertilizer application rates were based on soil sample analysis performed by the Soil Testing Laboratory at South Dakota State University. The fertilizer was applied at rates that would not limit the expected yields. All of the alfalfa fertilizer and a corn starter fertilizer containing about 10 percent of the total nitrogen and all of the phosphorus and potassium were applied to the plots each spring. The rest of the nitrogen was applied to the corn plots through the irrigation system in either two or three irrigations during the growing season.

All of the yield information was obtained by manually harvesting the plots. Yields for the corn plots were gathered by manually picking an area near the center of the plot that was 4 rows wide and 4.6 m (15 ft) long. The row spacing was 0.91 m (36 in). The corn was weighed on the cob to obtain the total wet weight. Cross sections of several

Table 3. Agronomic Information for Corn and Alfalfa Treatments at the Agricultural Engineering Farm (1973-1975).

Year	Crop	Planting Date	Population Plants/ha* (Plants/ac)	Harvest Date	Fertilization°° N kg/ha (lb/ac)	Fertilization°° P_2O_5 kg/ha (lb/ac)	Fertilization°° K_2O kg/ha (lb/ac)	Insecticide°° kg/ha (lb/ac)	Herbicide°° kg/ha (lb/ac)
								Bux 10	Atrazine
1973	Corn+	May 15	57,000**	Oct. 18	193	40	13	1.1	3.4
			(23,000)		(172)	(36)	(12)	(1)	(3)
	Alfalfa°	---	---	June 11	0	50	67	---	---
				July 16	(0)	(45)	(60)		
				August 29					
								Furadan	Atrazine
1974	Corn+	May 17	57,000**	Oct. 2	264	171	138	1.7	2.8
			(23,000)		(235)	(152)	(123)	(1.5)	(2.5)
	Alfalfa°	---	---	June 14	0	90	90	---	---
				July 20	(0)	(80)	(80)		
				Sept. 3					
								Furadan	Atrazine
1975	Corn+	May 15	49,000**	Nov. 4	193	86	139	1.7	2.8
			(20,000)		(172)	(77)	(124)	(1.5)	(2.5)
	Alfalfa°	---	---	June 26	10	50	121	---	---
				July 30	(9)	(45)	(108)		
				Sept. 8					

+Sokota TS 67 corn variety
°Certified vernal alfalfa variety
*At harvest
**Dryland plots thinned to approximately 37,000 plants/hectare (15,000 plants/acre)
°°Active material

ears from each sample were oven dried to determine the moisture content of the sample. The data were then used to compute the yield at 15 percent moisture. The alfalfa yields were handled in much the same way. The plot area was mowed with a standard sickle mower. The sample area, usually 4.6 m by 4.6 m (15 ft by 15 ft), was measured off in the center of each plot. The cut alfalfa in the sample area was collected and weighed. At the time of the weighing a moisture sample was also taken. The moisture samples were oven dried and the information was used to determine the yield in terms of dry matter. Figures 9 and 10 illustrate part of the harvesting procedure for the corn and alfalfa plots.

Figure 9. A Corn Plot Harvest Being Weighed.

Figure 10. An Alfalfa Plot Harvest Being Weighed and Sampled for Moisture.

ANALYSIS OF DATA AND RESULTS

Field Investigation

The main purpose of the field experiment was to gather yield data. These data were collected in order that yield estimates and economic analyses could be made. One of the first steps in evaluating the yield data was the completion of statistical analyses.

The individual plot yields used for the analyses are listed in Appendix C. The average yields for the individual treatments are indicated in Table 3a. Table 4 shows the analysis of variance for the corn yield data. The results of the analysis indicate that the treatment, year and treatment by year components are all statistically significant. The significance of the treatment component was further investigated by single degree of freedom partitions which are indicated in Table 5. The first partition compared dryland management to irrigated management. The highly significant F test along with the means listed in Table 3a indicate that the average yields of the irrigated treatments are higher than the dryland yield. The second partition basically compared the 2.5 cm (1 in) every 4 days treatments, 2C and 8C, to the 2.5 cm (1 in) every 7 days treatments. According to the 8A-8C management criteria, irrigation on the corn began about July 1. Since this was normally the time irrigation also began on treatment 2C, treatments 2C and 8C were basically the same. The significance of the comparison along with means listed in Table 3a indicate that on the average there is a higher yield associated with the higher irrigation frequency. Thus, under conditions similar to this experiment, a corn yield reduction would be expected when a center pivot machine is used on two fields rather than one.

Table 3a. Average Yields for Given Treatments.

Treatments	Average treatment yields from 1973-1975	
Corn	1000 kg/ha	(bu/acre)
1C	0.66	(10)
2C	8.31	(132)
5C1	6.96	(111)
5C2	6.98	(111)
6C	6.47	(103)
8C	8.48	(135)
Alfalfa	1000 kg/ha	(tons/acre)
3A	5.9	(2.62)
4A	11.3	(5.07)
6A	11.1	(4.95)
7A1	11.1	(4.96)
7A2	10.9	(4.83)
8A	8.8	(3.91)

Table 4. Analysis of Variance of the 1973-1975 Corn Yields.

Source	DF	SS	MS	MSE	F
Total	71	596.49			
Treatment	5	497.62	99.52	$Y\sigma^2_{R(T)} + RY\sigma^2_T$	82.93**
Year	2	24.70	12.35	$\sigma^2_{RY(T)} + RT\sigma^2_Y$	19.92**
Tmt. x Year	10	30.11	3.01	$\sigma^2_{RY(T)} + R\sigma^2_{TY}$	4.85**
Reps./Tmt.	18	21.64	1.20	$Y\sigma^2_{R(T)}$	
Years x Reps./Tmt.	36	22.42	0.62	$\sigma^2_{RY(T)}$	

**Significant at the 0.5% level.

Table 5. Single Degree of Freedom Partitions of Treatment Sum of Squares for Corn Yields.

Partition	SS	MS	F
1. 1C vs $(\overline{2C+5C1+5C2+6C+8C})$	459.05	459.05	382.54**
2. $(\overline{2C+8C})$ vs $(\overline{5C1+5C2+6C})$	36.20	36.20	30.17**
3. 5C1 vs 5C2	<0.01	<0.01	<0.01
4. 2C vs 8C	0.17	0.17	0.14
5. $(\overline{5C1+5C2})$ vs 6C	1.93	1.93	1.60

**Significant at the 0.5% level.

The last three partitions compared treatments which had the same basic irrigation frequencies. None of these comparisons were significant. A more in-depth analysis where the five partitions were compared on a yearly basis indicated there were no differences in the means of the 2.5 cm (1 in) every 7 days treatments. This analysis indicates that any irrigation timing effects due to moving a center pivot machine, which causes differing starting dates for an irrigation cycle on a particular field, have an insignificant effect on yield.

The significance of the year component of the analysis of variance in Table 4 indicates that the average yields differed depending on the year. The significance of the treatment by year interaction indicates that the relative magnitudes of the treatment yields, in relation to each other, were different in the various years of the experiment. The significance of the treatment by year component was caused, in part, by a relationship that was brought out in a more in-depth analysis. In 1974 the means of the high irrigation treatments, 8C and 2C, were not different from the means of treatments 5C1, 5C2 and 6C or the low irrigation treatments. In the other two years, however, the means of 8C and 2C were higher. The differences in these two years were great enough to statistically indicate that on the average there is a difference between the two irrigation levels.

The analysis of variance for the alfalfa yields is indicated in Table 6. The significance of the treatment component again indicates that there is a difference in yields depending on the treatment. As with the corn, the alfalfa treatment component was broken into single

Table 6. Analysis of Variance of the 1973-1975 Alfalfa Yields.

Source	DF	SS	MS	MSE	F
Total	215	587.61			
Treatments	5	94.14	18.83	$CY\sigma^2_{R(T)} + RCY\sigma^2_T$	35.53**
Cuttings	2	322.12	161.06	$Y\sigma^2_{RC(T)} + RTY\sigma^2_C$	644.24**
Years	2	27.48	13.74	$C\sigma^2_{RY(T)} + RCT\sigma^2_Y$	72.32**
Tmt. x Cut.	10	42.03	4.20	$Y\sigma^2_{RC(T)} + RY\sigma^2_{TC}$	16.80**
Tmt. x Years	10	5.90	0.59	$C\sigma^2_{RY(T)} + RC\sigma^2_{TY}$	3.11*
Cut. x Years	4	44.04	11.01	$\sigma^2_{RCY(T)} + RT\sigma^2_{CY}$	50.04**
Tmt. x Cut. x Years	20	10.43	0.52	$\sigma^2_{RCY(T)} + R\sigma^2_{TCY}$	
Reps./Tmt.	18	9.50	0.53	$CY\sigma^2_{R(T)}$	
Cut. x Reps./Tmt.	36	9.17	0.25	$Y\sigma^2_{RC(T)}$	
Years x Reps./Tmt.	36	6.75	0.19	$C\sigma^2_{RY(T)}$	
Cut. x Year x Reps./Tmt.	72	16.05	0.22	$\sigma^2_{RCY(T)}$	

**Significant at the 0.5% level.
*Significant at the 1.0% level.

Table 7. Single Degree of Freedom Partitions of Treatment Sum of Squares for Alfalfa Yields.

Partition	SS	MS	F
1. 3A vs $(\overline{4A+6A+7A1+7A2+8A})$	75.20	75.20	141.89**
2. 4A vs $(\overline{6A+7A1+7A2})$	0.27	0.27	0.51
3. 7A1 vs 7A2	0.17	0.17	0.32
4. 6A vs $(\overline{7A1+7A2})$	0.10	0.10	0.19
5. $(\overline{4A+6A+7A1+7A2})$ vs 8A	17.80	17.80	33.58**
6. 8A vs 3A°	16.40	16.40	30.94**

**Significant at the 0.5% level.
°A non-orthogonal comparison.

degree of freedom partitions as is shown in Table 7.

Partition 1 in Table 7 compared irrigated alfalfa to dryland alfalfa. The significant F test along with the means listed in Table 3a indicate that the average irrigated yield was greater than the dryland yield. The second partition had a nonsignificant F test. This comparison was between the treatment that received 2.5 cm (1 in) every 4 days and the average of the treatments that received 2.5 cm (1 in) every 7 days. The nonsignificant F test indicates that the increased irrigation frequency did not increase yield. Partitions 3 and 4, which compared the treatments that received 2.5 cm (1 in) every 7 days were also nonsignificant. Since there were no significant differences among the yields for treatments 4A, 6A, 7A1 and 7A2 an average value could be used to represent an estimate of yield for any of the respective treatments. Partition 5 compared the alfalfa yield of the alfalfa (early)-corn (late) management scheme to the average yield of the rest of the irrigated treatments. Partition 6 compared the alfalfa yield for the alfalfa (early)-corn (late) management scheme to the yield of the dryland management scheme. In both cases there were significant F tests. The significance of partitions 5 and 6 indicate that the yield of treatment 8A is different from both dryland alfalfa and alfalfa that is irrigated for the entire season. Partition 6 is a nonorthogonal partition or the information it gives overlaps some of the information already presented in the other five comparisons. It was decided before the statistical analysis that it is an important comparison and that it should be made even though it is not a completely independent partition.

A more in-depth analysis of the alfalfa yields is presented in Table 8, where the treatments are compared on a per cutting basis. The dryland yield, which is compared to the irrigated treatments in partition 1, is always lower than the average irrigated yield. The moisture content at the beginning of the growing season was typically about the same for all the treatments but in 1973 and 1975 the irrigated plots received at least one irrigation before the first cutting. This could have been one of the reasons why the irrigated plots had a slightly higher yield for the first cutting. Another possible reason for the higher yield in the first cutting was that the plant population decreased on the dryland plots as the experiment progressed.

One of the results of partition 2, Table 8, was unexpected. The yield for the first cutting of treatment 4A, 2.5 cm (1 in) every 4 days, was significantly lower than the mean of the yields for the 2.5 cm (1 in) every 7 days treatments. Although the lower yield was statistically significant, the actual difference only averaged 500 kg/ha (0.2 ton/acre). For the other cuttings treatment 4A had a slightly higher yield than the average yield of treatments 6A, 7A1 and 7A2, or the 2.5 cm (1 in) every 7 days treatments. The higher yields in the last two cuttings were not enough to make the yield of treatment 4A significantly higher than the 2.5 cm (1 in) every 7 days treatments when averaged over all three cuttings (Table 7).

In five out of the six comparisons presented in partitions 3 and 4, the yields for the 2.5 cm (1 in) every 4 days treatments did not vary significantly within any given cutting, which would basically

Table 8. Single Degree of Freedom Comparison of Alfalfa Treatment Partitions on a Per Cutting Basis.

Partition	Cutting 1		Cutting 2		Cutting 3	
	SS	F	SS	F	SS	F
1. 3A vs $\overline{(4A+6A+7A1+7A2+8A)}$	2.04	8.16**	70.43	281.72***	28.02	112.08***
2. 4A vs $\overline{(6A+7A1+7A2)}$	2.26	9.04***Δ	1.49	5.96*	1.40	5.60*
3. 7A1 vs 7A2	0.26	1.04	1.19	4.76*	0.77	3.08
4. 6A vs $\overline{(7A1+7A2)}$	0.10	0.40	0.14	0.56	0.25	1.00
5. 8A vs $\overline{(4A+6A+7A1+7A2)}$	0.18	0.72	3.88	15.52***	24.06	96.24***
6. 3A vs 8A°	0.70	2.80	27.61	110.44***	1.00	4.00

°A non-orthogonal comparison.
*Significant at the 5.0% level.
**Significant at the 1.0% level.
***Significant at the 0.5% level.
ΔThe mean of $\overline{(6A+7A1+7A2)}$ is higher than the mean of 4A for the first cutting.

indicate that the yields for treatments 6A, 7A1 and 7A2 all respond to the irrigation in the same manner. Comparisons made in partitions 5 and 6 together with the other comparisons indicate how the alfalfa yield from the alfalfa (early)-corn (late) management scheme differs from the yield for the dryland scheme and the schemes where the alfalfa is irrigated over the entire season. The yield of treatment 8A is not significantly different from either the dryland yield (comparison 6) or the yields from the other irrigated plots (comparison 5) for the first cutting. The second cutting yield of treatment 8A is higher than the dryland yield but lower than the average yield of the irrigated plots. Although it is different from both, its yield approaches that of the irrigated plots. The third cutting yield of treatment 8A is about the same as the dryland yield, which is significantly below the yields of the other irrigated plots. The relative changing of the magnitudes of the individual cutting yields of treatment 8A compared to the other treatments is probably in part why the treatment by cutting component in Table 6 is significant.

The significance of the cutting component of Table 6 indicates that the average yield per cutting varies depending on the cutting. The yields decrease with each successive cutting. A significant F test on the years component simply means that the average yield varies from year to year.

The significance of the treatment by year and cutting by year components of Table 6 means that the relative relationship of the magnitude of yields to the treatments vary depending upon the year and that the relative relationship of the magnitude of yields for a given cutting vary depending upon the year. An example of the second situation may be illustrated by looking at the dryland yields for the second and third cuttings, Table C2 (Appendix C). In 1973 the yield for cutting 2 was higher than the yield for cutting 3. Due to rainfall late in the 1975 season, the yield for cutting 3 was higher than the yield for cutting 2. Any of the components that deal with years could be expected to be significant since there are many uncontrolled variables such as temperature, rainfall, sunshine etc. which affect yield and vary from year to year.

The statistical analyses basically show that there are some differences among both the corn and the alfalfa treatments. In the corn treatments, the yields for the 2.5 cm (1 in) every 4 days treatments, including the corn (late) treatment, were higher than the yields for the 2.5 cm (1 in) every 7 days treatments and the yields for the 2.5 cm (1 in) every 7 days treatments were higher than the dryland yield. The other comparisons of the treatments showed no significant differences in yield.

The statistical analyses of the alfalfa yields indicated that there was basically a difference between the dryland and the irrigated treatments. The yield from the alfalfa treatment irrigated 2.5 cm (1 in) every 4 days was not significantly different from the yields of the treatments irrigated 2.5 cm (1 in) every 7 days. For the first cutting the yield for the alfalfa (early) treatment was not different from either the irrigated or the dryland yield. The yield for the alfalfa (early) treatment was lower than the irrigated treatments but was still higher than the dryland treatment for the second cutting. The alfalfa (early) treatment yield was about the same as the dryland yield for the third cutting.

One of the uncontrolled variables that probably had the most effect on yield was rainfall. The rainfall during a major part of the growing season was below normal for all three years of the research. Figure 11 indicates the deviation of the rainfall from normal. The actual amounts of precipitation are listed in Appendix D. Precipitation during the months of July and August was especially low. The dryer than normal conditions would have made the crops more dependent on irrigation than normal and any differences in yields found in this research may be greater than differences in a normal year.

The soil moisture depletion curves in Appendix B indicate moisture level fluctuations during the growing seasons. Moisture samples obtained in the field indicated that moisture was withdrawn below the laboratory evaluated permanent wilting point. The moisture samples that were obtained from the field represented an average moisture content for the entire 46 cm (18 in) profile. A reason why the moisture content went so low may have been that evaporative losses from the soil surface lowered the moisture content of the upper part of the profile well below the permanent wilting point and thus lowered the average moisture content of the entire profile. The lowest sample had a moisture content of approximately 5 cm (2 in) so this value, rather than the permanent wilting point, was chosen as the minimum level for the calculated soil

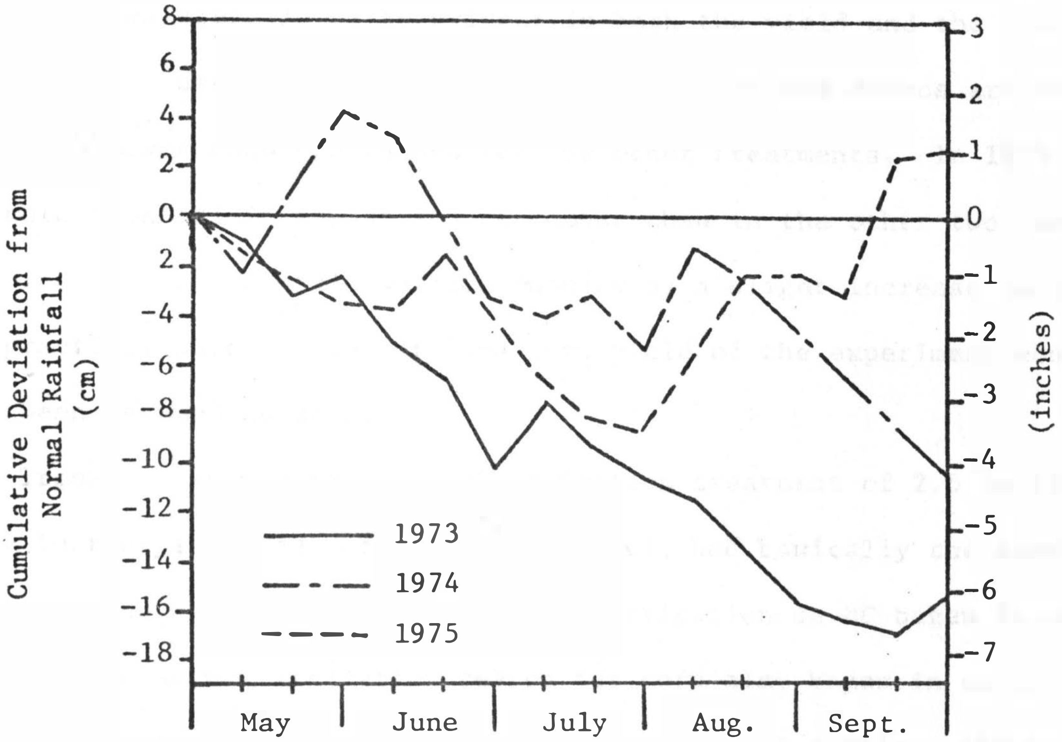

Figure 11. Comparison of Rainfall During the Years of the Experiment to Normal Rainfall.

moisture presented in Appendix B.

Winter recharge was assumed to bring the soil profile to field capacity at the beginning of the growing season in 1974 and 1975. In 1973 the soil moisture content at the beginning of the growing season was estimated to be 11 cm (4.3 in). The field moisture samples show only fair agreement with the calculated curves, however, they generally agree well enough that the trend of the moisture depletion can be represented by the calculated curve.

The moisture level in treatment 1C (dryland corn, Figure B1, Appendix B) went below the permanent wilting point for a considerable part of July, August and September during all three years. The effect of the low moisture level is evident in both the yield and the evapotranspiration data presented in Table 9. The dryland values are considerably lower than the values for the other treatments. In 1975 there was more rainfall in August and September than in the other two years. This increase in rainfall was accompanied by a slight increase in yield. For practical purposes the dryland corn yield of the experiment could have been assumed as zero.

Treatment 2C was the maximum irrigation treatment of 2.5 cm (1 in) every four days. Treatment 8C, corn (late), had basically the same irrigation scheme as treatment 2C since irrigation on 8C began in early July and the normal irrigation season for corn also began in early July. Since the irrigation of the two treatments was very similar, the moisture depletion curves for treatment 2C, Figure B2, are also representative of the depletion curves for treatment 8C. Figure B2 indicates that the moisture level was generally adequate during the experimental years. The moisture levels generally remained above 50 percent available moisture. Table 9 indicates that the yields associated with these treatments are higher than the yields associated with the lower irrigation rate. The irrigation dates and amounts are indicated both in Appendix B and Appendix C. The initiation of irrigation was late in 1975, however, the simulated system had sufficient capacity to bring the moisture level back to near field capacity.

The timing of the irrigations, indicated on the moisture depletion curves and also in Appendix D, illustrated one problem in the experimental procedure. The experimental set up was such that the plots could be

Table 9. Seasonal Yield and Moisture Use Data for Corn.

Treatment	Year	Average yield° 1000 kg/ha (Bu/acre)	Seasonal* rainfall cm (in)	Seasonal irrigation cm (in)	Seasonal drainage cm (in)	Seasonal evapotrans-piration cm (in)	Decrease in soil moisture storage cm (in)
1C	1973	0.47 (7.5)	16.6 (6.55)	0 (0)	0 (0)	21.4 (8.42)	4.75 (1.87)
	1974	0.11 (1.7)	22.7 (8.94)	0 (0)	7.28 (2.87)	24.9 (9.80)	9.50 (3.74)
	1975	1.41 (22.6)	33.4 (13.10)	0 (0)	5.52 (2.17)	32.3 (12.70)	4.33 (1.70)
	Average	0.66 (10.6)	24.2 (9.53)	0 (0)	4.27 (1.68)	26.2 (10.30)	6.19 (2.44)
2C	1973	8.91 (142.0)	16.6 (6.55)	35.9 (14.10)	5.01 (1.98)	45.3 (17.80)	-2.24 (-0.88)
	1974	7.10 (113.0)	22.7 (8.94)	38.1 (15.00)	17.20 (6.77)	45.9 (18.10)	2.36 (0.93)
	1975	8.91 (142.0)	33.4 (13.10)	25.4 (10.00)	14.90 (5.87)	45.2 (17.80)	1.25 (0.49)
	Average	8.31 (132.0)	24.2 (9.53)	33.1 (13.00)	12.40 (4.87)	45.5 (17.90)	0.45 (0.18)
5C1	1973	8.24 (131.0)	16.6 (6.55)	34.2 (13.50)	5.64 (2.22)	43.9 (17.30)	-1.24 (-0.49)
	1974	7.39 (118.0)	22.7 (8.94)	27.9 (11.00)	9.71 (3.82)	45.0 (17.70)	4.07 (1.60)
	1975	5.24 (83.0)	33.4 (13.10)	20.3 (8.00)	11.10 (4.37)	43.9 (17.30)	1.25 (0.49)
	Average	6.96 (111.0)	24.2 (9.53)	27.5 (10.80)	8.82 (3.47)	44.3 (17.40)	1.36 (0.53)
5C2	1973	7.80 (124.0)	16.6 (6.55)	36.4 (14.30)	5.95 (2.34)	43.5 (17.10)	-3.54 (-1.39)
	1974	6.79 (108.0)	22.7 (8.94)	33.0 (13.00)	13.20 (5.19)	45.3 (17.80)	2.83 (1.11)
	1975	6.35 (101.0)	33.4 (13.10)	20.3 (8.00)	11.60 (4.57)	43.4 (17.10)	1.25 (0.49)
	Average	6.98 (111.0)	24.2 (9.53)	29.9 (11.70)	10.20 (4.03)	44.1 (17.30)	0.18 (0.07)
6C	1973	7.44 (118.0)	16.6 (6.55)	33.4 (13.10)	2.44 (0.96)	44.0 (17.30)	-3.54 (-1.39)
	1974	5.94 (95.0)	22.7 (8.94)	33.0 (13.00)	12.50 (4.92)	45.1 (17.80)	1.89 (0.74)
	1975	6.05 (96.0)	33.4 (13.10)	20.3 (8.00)	11.60 (4.57)	43.4 (17.10)	1.25 (0.49)
	Average	6.47 (103.0)	24.2 (9.53)	28.9 (11.40)	8.85 (3.48)	44.2 (17.40)	-0.13 (-0.05)
8C	1973	9.93 (158.0)	16.6 (6.55)	36.4 (14.30)	4.66 (1.83)	44.8 (17.60)	-3.55 (-1.40)
	1974	7.45 (119.0)	22.7 (8.94)	35.6 (14.00)	17.20 (6.77)	45.7 (18.00)	4.62 (1.82)
	1975	8.04 (128.0)	33.4 (13.10)	27.9 (11.00)	17.30 (6.81)	45.3 (17.80)	1.25 (0.49)
	Average	8.48 (135.0)	24.2 (9.30)	33.3 (13.10)	13.00 (5.14)	45.3 (17.80)	0.77 (0.30)

°Yields are expressed in terms of grain at 15 percent moisture.
*Seasonal values based on data from May 15 to September 16.

irrigated only when the wind was low. High winds occasionally caused irrigations to be delayed. Since a center pivot would generally not be shut down at the wind velocities which prohibited plot irrigation, the delays in plot irrigation were allowed to affect the timing but not the seasonal amount of irrigation.

Treatment 5C1 along with treatments 5C2 and 6C received an irrigation frequency of 2.5 cm (1 in) every 7 days. A typical moisture depletion curve is shown in Figure B3. It can be seen that the moisture level went below the 50 percent available moisture level and even went below the permanent wilting point in 1975. The yields for these treatments as presented in Table 9 were lower than the yields for treatments 2C and 8C, but still considerably higher than the yield for the dryland treatment.

In all the corn treatments, except dryland, the soil moisture conditions were adequate for substantial yields. In 1975 the irrigation was started a little late but the dry month of July probably had more of an effect on low moisture level than the late irrigation start. Generally the yields decreased with decreasing irrigation frequencies, or in other words a yield reduction could be expected by using a center pivot machine on two fields rather than one.

The soil moisture condition in the dryland alfalfa, treatment 3A, was very low. Figure B4 (Appendix B) indicates that the moisture level was below the permanent wilting point much of the growing season. The moisture condition was lowest in 1973 and highest in 1975. Table 10 correspondingly indicates the lowest dryland yield in 1973 and the highest in 1975. The dryland seasonal evapotranspiration indicated in Table 10

Table 10. Seasonal Yield and Moisture Use Data for Alfalfa.

Treatment	Year	Total average yield° 1000 kg/ha (tons/acre)	Seasonal* rainfall cm (in)	Seasonal irrigation cm (in)	Seasonal drainage cm (in)	Seasonal evapotrans-piration cm (in)	Decrease in soil moisture storage cm (in)
3A	1973	4.81 (2.15)	20.8 (8.19)	0 (0)	0 (0)	23.4 (9.21)	2.49 (0.98)
	1974	5.42 (2.42)	26.5 (10.40)	0 (0)	1.10 (0.43)	34.9 (13.70)	9.50 (3.74)
	1975	7.39 (3.30)	37.6 (14.80)	0 (0)	0 (0)	43.0 (16.90)	5.38 (2.12)
	Average	5.87 (2.62)	28.3 (11.10)	0 (0)	0.37 (0.14)	33.8 (13.30)	5.79 (2.28)
4A	1973	10.20 (4.57)	20.8 (8.19)	46.0 (18.10)	4.31 (1.62)	59.4 (23.40)	-3.35 (-1.32)
	1974	12.20 (5.46)	26.5 (10.40)	40.6 (16.00)	8.20 (3.23)	67.1 (26.40)	8.06 (3.17)
	1975	11.60 (5.17)	37.6 (14.80)	34.9 (13.70)	10.20 (4.02)	64.8 (25.50)	2.49 (0.98)
	Average	11.30 (5.07)	28.3 (11.10)	40.5 (15.90)	7.51 (2.96)	63.8 (25.10)	2.40 (0.94)
6A	1973	9.83 (4.38)	20.8 (8.19)	33.0 (13.00)	0 (0)	53.4 (21.10)	-0.48 (-0.19)
	1974	12.20 (5.46)	26.5 (10.40)	35.6 (14.00)	3.45 (1.36)	66.4 (26.10)	7.75 (3.05)
	1975	11.30 (5.02)	37.6 (14.80)	24.8 (9.76)	3.73 (1.47)	61.2 (24.10)	2.49 (0.98)
	Average	11.10 (4.95)	28.3 (11.10)	31.1 (12.20)	2.39 (0.94)	60.3 (23.70)	3.25 (1.28)
7A1	1973	9.29 (4.14)	20.8 (8.19)	33.3 (13.10)	0 (0)	53.9 (21.20)	-0.22 (-0.09)
	1974	11.20 (4.99)	26.5 (10.40)	35.6 (14.00)	6.43 (2.53)	64.8 (25.50)	9.11 (3.59)
	1975	12.90 (5.76)	37.6 (14.80)	27.3 (10.70)	4.27 (1.68)	63.2 (24.90)	2.49 (0.98)
	Average	11.10 (4.96)	28.3 (11.10)	32.1 (12.60)	3.57 (1.40)	60.6 (23.90)	3.79 (1.49)
7A2	1973	8.98 (4.01)	20.8 (8.19)	30.5 (12.10)	0 (0)	52.1 (20.50)	0.73 (0.29)
	1974	11.40 (5.06)	26.5 (10.40)	38.1 (15.10)	5.97 (2.35)	66.4 (26.10)	7.75 (3.05)
	1975	12.20 (5.43)	37.6 (14.80)	27.3 (10.70)	5.12 (2.02)	62.3 (24.50)	2.49 (0.98)
	Average	10.90 (4.83)	28.3 (11.10)	32.0 (12.60)	3.70 (1.46)	60.3 (23.70)	3.66 (1.44)
8A	1973	7.30 (3.26)	20.8 (8.19)	18.0 (7.09)	0 (0)	40.4 (15.90)	1.55 (0.61)
	1974	8.80 (3.93)	26.5 (10.40)	12.7 (5.00)	3.39 (1.33)	45.3 (17.80)	9.50 (3.74)
	1975	10.20 (4.55)	37.6 (14.80)	12.1 (4.76)	0 (0)	55.1 (21.70)	5.38 (2.12)
	Average	8.77 (3.91)	28.3 (11.10)	14.3 (5.62)	1.13 (0.44)	46.9 (18.50)	5.48 (2.16)

°Yields are expressed in terms of dry matter.
*Seasonal values based on data from May 1 to September 27.

also increased with increased rainfall. It would appear that the soil generally had enough storage capacity to hold rainfall and that this stored water was used in evapotranspiration.

The moisture depletion curves for treatment 4A, Figure B5, indicate that during all three years the moisture level was allowed to become very low near the beginning of the season. The only year, however, that the 2.5 cm (1 in) every 4 days irrigation frequency was not able to bring the moisture level back to near field capacity by mid to late June was 1975. The somewhat low moisture levels for treatment 4A in June and July of 1975 did not seem to adversely affect the total seasonal yields as indicated in Table 10. The high seasonal yields in 1975, however, could have been caused by the high rainfall late in the season. Treatment 4A as well as some of the other treatments also had irrigations larger than 2.5 cm (1 in) in June of 1974 and 1975. These irrigations were intended to help compensate for the late irrigation start.

The moisture depletion curves for treatments 6A and 7A1 are similar to the moisture depletion curves for treatment 7A2 shown in Figure B6. The moisture level of these treatments, which received 2.5 cm (1 in) every 7 days, was generally only slightly poorer than the moisture level of the 2.5 cm (1 in) every 4 days treatment indicated in Figure B5. The yields indicated in Table 10 are correspondingly only slightly lower. The dryest year, 1973, had the lowest yields as could be expected.

Treatment 8A was the treatment simulating the situation where alfalfa is irrigated by a center pivot until about the first of July. The soil moisture depletion curves shown in Figure B7 indicate that the moisture level was considerably better than dryland until about mid-July, after which it was about the same as the dryland level. Before early July, treatment 8C was basically the same as treatment 4A which had an irrigation capacity of 2.5 cm (1 in) every 4 days. The irrigation on these plots generally did not begin early enough. The moisture situation could have been improved considerably in the early part of the growing season in 1973 and 1975 by starting the irrigation on an earlier date. In 1975 the irrigation on treatment 8A was continued slightly longer than the management criteria prescribed so that the moisture level would be more nearly what it should have been if irrigation had begun earlier. The low moisture levels for treatment 8A in the early part of the 1973 and 1975 growing seasons did not seem to have a major effect on the yields presented in Table 10, however the high rainfall in August of 1975 may account for some of the high yield obtained that year.

In general the average seasonal soil moisture content of both the alfalfa and corn plots decreased as the amount of irrigation decreased. The drier conditions were usually reflected in lower seasonal evapotranspiration and in lower yields. Alfalfa yields were not as sensitive to low moisture conditions as the corn yields. The soil generally ended the growing season with some moisture depleted from storage, and the amount depleted generally increased as the frequency of irrigation decreased.

The low moisture holding capacity of the shallow soil caused a situation where the soil moisture could drop quite rapidly from field capacity to the permanent wilting point. Even with systematic irrigation the moisture levels of the plots fluctuated considerably as is indicated in the moisture depletion curves (Appendix B). Low storage capacity along with the below normal rainfall was probably one of the reasons for the low dryland yields. The storage capacity of the soil was also probably one of the reasons why there was considerable drainage (Tables 9 and 10). It is doubtful that such high yields could have been maintained in this experiment if an irrigation policy that favored decreased drainage had been used.

The calculated seasonal values of evapotranspiration and the average treatment yields were used in a linear regression of yield on evapotranspiration. The regression curve for corn, present in Figure 12, is described by the following equation:

$$Y = -8.25 + 0.350\ ET \qquad \text{Equation 1}$$

where

Y = grain yield, 1000 kg/ha at 15% moisture

ET = calculated seasonal evapotranspiration, cm

There have been other published experiments in which crop yields and evapotranspiration have been measured or estimated. The expressions in Table 11 represent some of these relationships expressed in terms of the same units associated with Equation 1.

The relationship derived in this research seems to be comparable to the relationships presented in Table 11. The regression agrees most closely with the work done in Israel by Hillel and Guron (1973). Results from the two California projects (Stewart et al. 1975, Stewart and Hagan

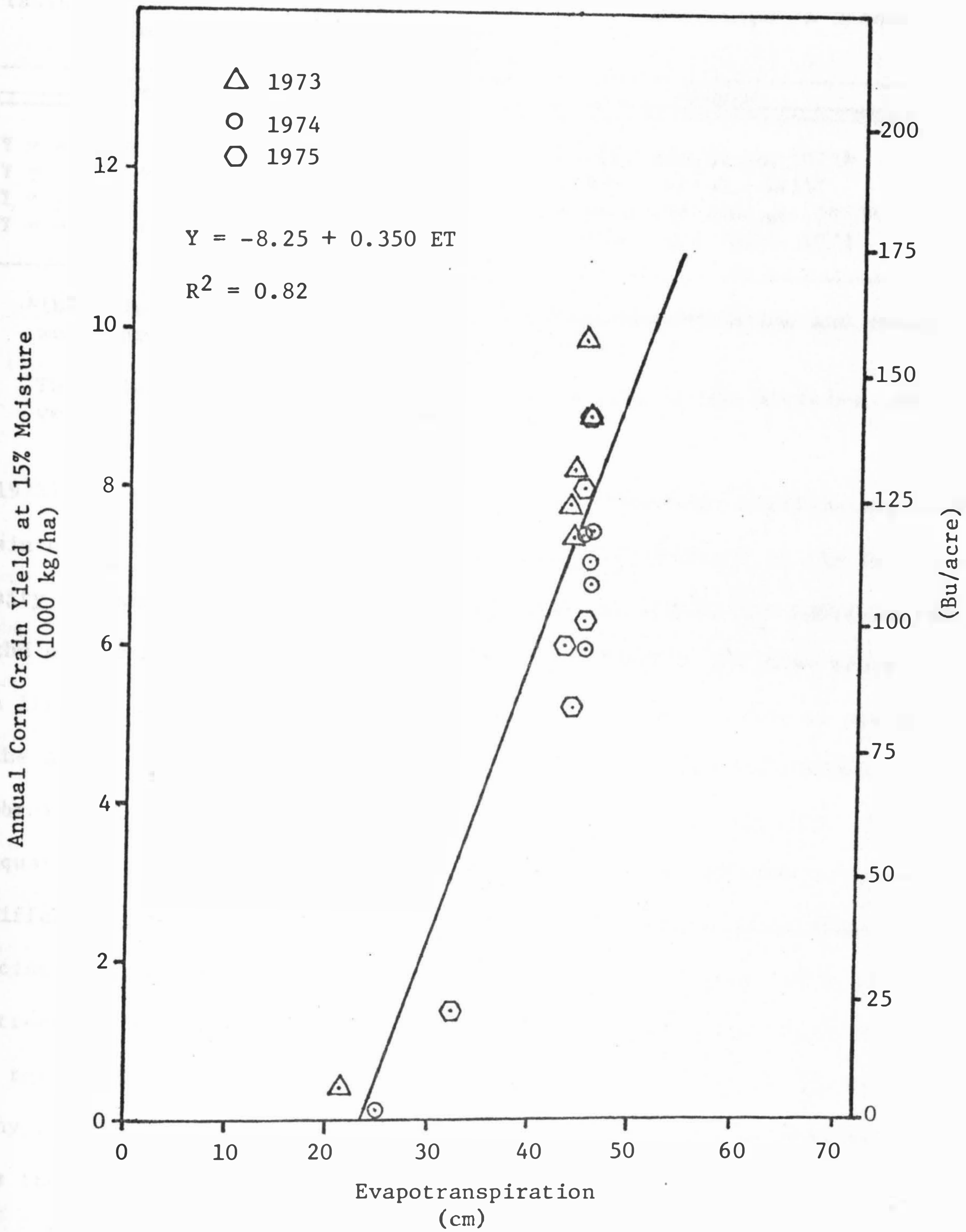

Figure 12. Linear Regression of Corn Yield on Seasonal Evapotranspiration.

Table 11. Corn Yield and Evapotranspiration Relationships as Determined from Other Research.

Relationship	Source
Y = -10.24 + 0.372 ET	Hillel and Guron 1973*
Y = -3.03 + 0.231 ET	Stewart et al. 1975°
Y = -0.123 + 0.142 ET	Robins and Domingo 1953*
Y = -3.99 + 0.262 ET	Stewart and Hagan 1973°

*The relationships are calculated from evapotranspiration and yield means presented in the respective articles.

°The relationships are the equations presented in the articles converted to the units used in this research.

1973) agree quite well with each other. The agreement could be expected since the crops were grown in similar soils and climates at the University of California at Davis. Assuming that the yields are approximately the same magnitude or are clustered in approximately the same manner, a little flatter slope would mean a higher intercept, which is apparently the difference between the Davis relationships and the relationships obtained in this research and in the Hillel and Guron research. The equation based on the Robins and Domingo (1953) data appears to be quite different from the rest. The relationship was based on data where severe moisture stresses were applied at specific growth stages. If a severe stress is imposed at a critical stage, there may be a low yield and yet a relatively high seasonal evapotranspiration. This may be one reason why the curve is less steep or is not as sensitive to evapotranspiration as the other equations indicate.

The data points for the corn regression tended to be quite clustered, with all but three of the evapotranspiration values in 40 to

50 cm (15.7 to 19.7 in) range. The steep slope of the prediction equation together with the clustered points gave a fairly high correlation (R^2 = 0.82) even though there was considerable yield variation within the 40 to 50 cm evapotranspiration range. The prediction equation for corn does not appear to accurately represent the yield throughout the entire 40 to 50 cm evapotranspiration range. If the prediction equation is to be used to estimate yields an estimate of evapotranspiration must first be made. Inasmuch as most of the treatments considered in this study have estimated evapotranspirations in this range, there may be some error if the prediction equation is used to obtain yield estimates. Since the treatments simulated the actual management schemes that were being investigated it is believed that using the experimental treatment means for yield estimates in the subsequent economic analysis will be more accurate than using yield estimates obtained from the prediction equation.

A linear regression analysis was also performed on the average seasonal alfalfa yield data and the calculated seasonal evapotranspiration data. The regression curve is plotted in Figure 13. The following prediction equation was derived from the analysis:

$$Y = -0.138 + 0.184\ ET \qquad \text{Equation 2}$$

where

Y = Seasonal dry matter yield, 1000 kg/ha

ET = Seasonal evapotranspiration, cm

Investigations conducted by other researchers led to the relationships presented in Table 12, which are expressed in the same units as Equation 2.

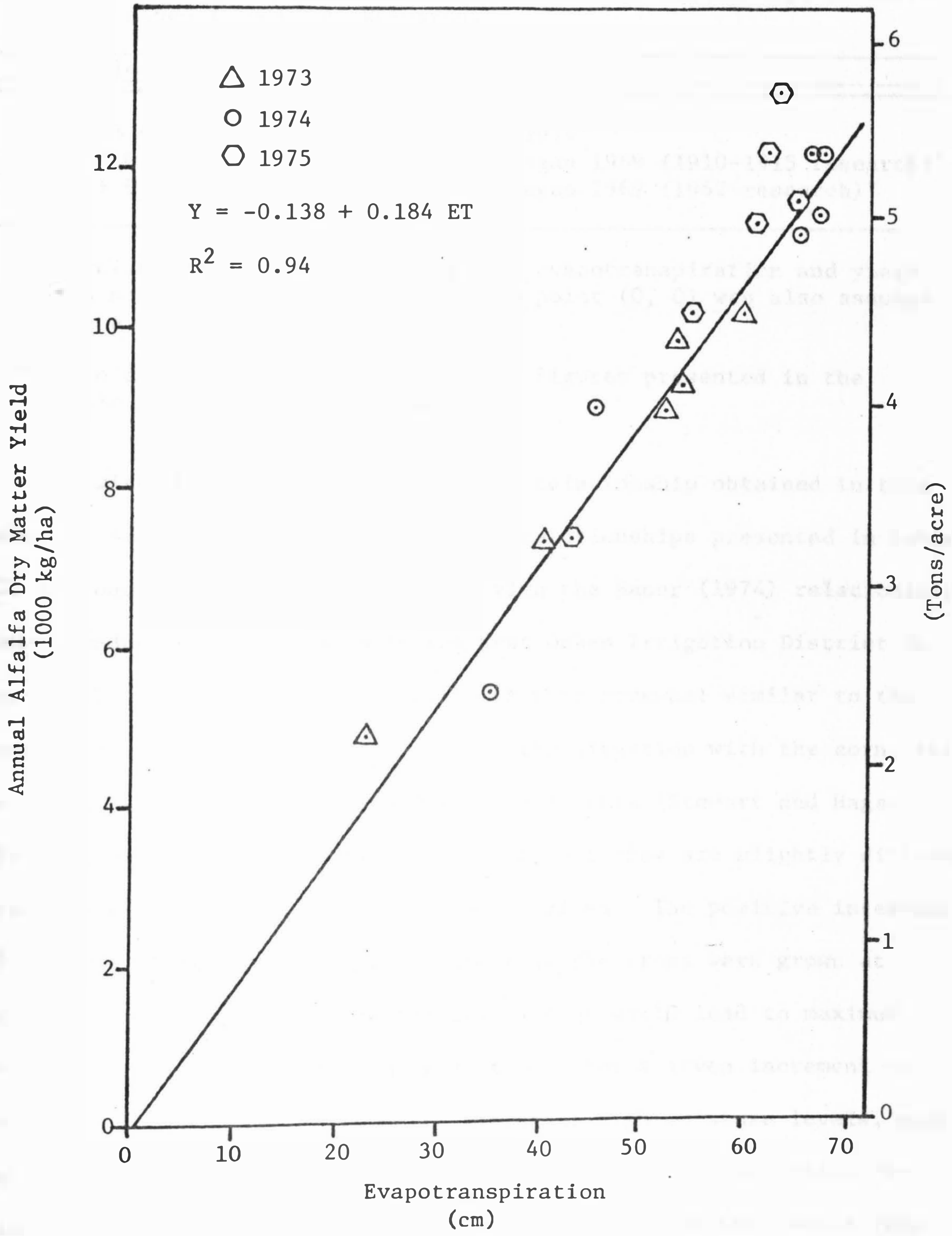

Figure 13. Linear Regression of Seasonal Alfalfa Yield on Seasonal Evapotranspiration.

Table 12. Alfalfa Yield and Evapotranspiration Relationships as Determined from Other Research.

Relationship	Source
Y = −0.028 + 0.19 ET	Bauer et al. 1974+
Y = 2.4 + 0.17 ET	Stewart and Hagan 1969 (1910-1915 research)°
Y = 4.9 + 0.15 ET	Stewart and Hagan 1969 (1962 research)°

+The relationship was calculated from evapotranspiration and yield means presented in the article. The point (0, 0) was also assumed to be a data point.

°The relationships are estimated from figures presented in the article.

As with the corn data, the alfalfa relationship obtained in this research seems to be comparable to the relationships presented in Table 12. The equation agrees most closely with the Bauer (1974) relationship. Bauer conducted his research in the West Oakes Irrigation District in North Dakota so the climatic conditions were somewhat similar to the conditions in this experiment. As was the situation with the corn, the two alfalfa relationships from Davis, California (Stewart and Hagan 1969) agree quite closely with each other but they are slightly different from the relationships obtained at other sites. The positive intercept of the two relationships may indicate that the crops were grown at moisture levels near or above the levels that would lead to maximum evapotranspiration and maximum production. For a given increment of evapotranspiration the incremental yields at high moisture levels, near maximum production, may not be as high as the incremental yields resulting at a lower moisture level. An effect such as this would tend to decrease the slope and increase the intercept of a linear relationship.

This factor along with the assumption that the intercept should be zero indicate that a curvilinear relationship may be appropriate for the Davis data.

The alfalfa data in this research have a high correlation (R^2 = 0.93) with a linear relationship. The prediction equations of both this research and Bauer's research have an intercept which is very close to zero. The two slopes of the two equations are also approximately equal. These two factors support the theory that, at least for first order results, alfalfa yield is directly proportional to evapotranspiration. Although the alfalfa regression had a higher correlation than the corn data it was again decided to use the means of the respective treatments for estimates of yield in the following economic analyses rather than the prediction equation.

A summary of the yield estimates based on treatment means is presented in Table 13. If there were no statistical differences among the yields of different treatments, the yields were estimated by an average of the means.

Thus far two basic types of production functions have been presented. A production function defines a relationship between crop yield and some variable. The first type of production function related yield to a continuous variable, which was evapotranspiration in this case (Equations 1 and 2). The second type of production function related yield to a discrete variable. The discrete variable consisted of the individual management schemes (Table 13). Although both types of functions can be used to estimate yields, the second type was used

Table 13. Estimated Yields for Given Management Schemes.

	Yield			
	Corn°		Alfalfa+	
Management Scheme	1000 kg/ha	(bu/acre)	1000 kg/ha	(tons/acre)
One center pivot used on one field	8.40	(133)	11.10	(4.95)
One center pivot used on two fields	6.80	(108)	11.10	(4.95)
Alfalfa irrigated until the end of June	---	---	8.77	(3.91)
Corn irrigated after the end of June	8.40	(133)	---	---
Dryland	0.66	(10)	5.87	(2.62)

°Corn yield expressed in terms of grain at 15% moisture.
+Alfalfa yield expressed in terms of dry matter.

for the subsequent economic analysis.

Economic Investigation

The economic study consists basically of using yield estimates as well as other factors particular to individual management schemes to determine annual costs and annual returns. Some of the cost and return values used in the analyses are listed in Table 14. The values are based on the information listed in Appendix A.

Table 15 summarizes experimental data as well as some fundamental inferences based on the data and the previous assumptions. The seasonal irrigation depth, number of irrigations and number of moves are based on values that were observed in the field experiment. Expected yields are based on treatment means and on the statistical analyses as presented in

Table 14. Assumed Cost and Return Information.

Item	Cost
Electricity	\$12.70/measured kw (\$9.50/measured hp)--standby \$0.019/kw-hr--service
Well and casing	\$164/m (\$50/ft)
Pump, motor and panel	\$7700-56 kw (75 hp) \$8000-75 kw (100 hp)
Center pivot machine	\$32,900
Mainline	\$8.40/m (2.60/ft) plus \$300 for going into or coming out of ground
Extra pivot pad	\$350
Labor	\$3.25/hr
Price of corn°	\$98.20/1000 kg (\$2.50/bu)
Price of alfalfa+	\$55.00/1000 kg (\$50/ton)

°Corn at 15% moisture.
+Alfalfa price stated in terms of alfalfa at 12% moisture. The prices in terms of dry matter are \$63.70/1000 kg (\$57.90/ton).

Table 15. Irrigation and Yield Data for Land Managed Under Given Irrigation Management Schemes.

Management scheme	Seasonal irrigation depth cm (in) Field 1*	Field 2	Total	No. of irrigations	No. of moves	Labor involved in moving++	Hours of pumping	Total operating head m (ft)Δ	Power requirements kw (hp)ΔΔ	Length of mainline required m (ft)	Expected yield+ 1000 kg/ha Field 1*	Field 2
Corn Dryland Tmt. 1C	---	---	0 (0)	0	0	0	0	---	---	---	0.66 (10)	---
Corn 1 C.P./1 field Tmt. 2C	33.1 (13)	---	33.1 (13)	13	0	0	965**	80 (263)	59.7 (80)	0	8.40 (133)	---
Corn-corn 1 C.P./2 fields Tmts. 5C1, 5C2	28.5 (11.2)	28.5 (11.2)	57.0 (22.4)	22	22	220	1320••	82 (270)	74.6 (100)	804 (2640)	6.80 (108)	6.80 (108)
Alfalfa-corn 1 C.P./2 fields Tmts. 6A, 6C	31.1 (12.2)	28.9 (11.4)	60.0 (23.6)	24	22•	220	1380••	82 (270)	74.6 (100)	804 (2640)	11.10 (4.95)	6.80 (108)
Alfalfa-alfalfa 1 C.P./2 fields Tmts. 7A1, 7A2	32.0 (12.6)	32.0 (12.6)	64.0 (25.2)	25	25	250	1480••	82 (270)	74.6 (100)	804 (2640)	11.10 (4.95)	11.10 (4.95)
Alfalfa 1 C.P./1 field Tmt. 4A	40.5 (15.9)	---	40.5 (15.9)	16	0	0	1175**	80 (263)	59.7 (80)	0	11.10 (4.95)	---
Alfalfa Dryland Tmt. 3A	---	---	0	0	0	0	0	---	---	---	5.87 (2.62)	---
Alfalfa (early) -corn (late) 1 C.P./2 fields Tmts. 8A, 8C	14.3 (5.6)	33.3 (13.1)	47.6 (18.7)	19	2	20	1100••	82 (270)	74.6 (100)	804 (2640)	8.77 (3.91)	8.40 (133)

*In alfalfa-corn cropping combinations Field 1 is alfalfa, Field 2 is corn.

++10 man hours per move.

ΔThe head is based on 53 m (175 ft) pressure at the pivot, 26 m (85 ft) lift and either 1 m (3.3 ft) head loss for 3.0 m^3/min or 3 m (10 ft) head loss for 3.8 m^3/min flowing through 400 m of mainline.

ΔΔPower requirements are based on a pump efficiency of 80% and a motor efficiency of 95% plus an additional 7.46 kw (10 hp) to run the system.

+The yield in parenthesis is represented in Tons/acre for alfalfa and Bu/acre for corn. All yields reported as dry matter for alfalfa, grain at 15% for corn.

•The alfalfa is assumed to be irrigated twice before the system is moved to the corn.

**Pumping rate is 3.0 m^3/min (800 gpm). The pump motor size required is at least 49 kw (66 hp).

••Pumping rate is 3.8 m^3/min (1000 gpm). The pump motor size required is at least 63 kw (85 hp).

Table 13.

Estimated annual fixed costs are presented in Table 16. The original investment costs came from the estimates listed in Table 14. Estimated lives of the various components are based in part on the estimates presented in other references (Turner et al. 1971, Kerr 1975, Stegman 1975). The annual fixed costs do not include interest for original land investment nor any real estate taxes other than increases due to the increased value of irrigated land over dryland.

The annual production costs, listed in Table 17, are estimates by the author based on information from Pahl (1976). Production costs are estimates of expenses that would be incurred by the management associated with production of the yields estimated in the experiment. The costs also reflect the prices in the general geographic location of the experiment.

Table 18 represents a general summary of all the costs and returns for the various management schemes. The electrical costs were calculated on the basis of a standby charge and a charge for the power consumed. The standby and service charge is a typical billing policy for power utilities in South Dakota. The additional labor charges are costs that are due to the increased labor involved in moving a system. Total annual costs consist of electrical costs, annual fixed costs, annual production costs and additional labor costs. The return to land and management is the expected gross return, based on the commodity prices listed in Table 14, minus the total annual costs. These returns again do not include costs associated with land values.

Table 16. Annual Fixed Costs for Given Irrigation Management Schemes.

Management scheme	Well° and casing Initial cost	Well° and casing Life yrs.	Well° and casing Annual cost++	Pump, motor, panel Initial cost	Pump, motor, panel Life yrs.	Pump, motor, panel Annual cost++	Center pivot machine Initial cost	Center pivot machine Life yrs.	Center pivot machine Annual cost++	Mainline+ Initial cost	Mainline+ Life yrs.	Mainline+ Annual cost++	Insurance on C.P.	Personal property tax on C.P.°°	Sub-total	Added real estate tax* per ha (per acre)	Added interest on land investment per ha** (per acre)	Total costs per ha (per acre)
Corn Dryland Tmt. 1C		---			---			---			---		---	---	0	0	0	0
Corn 1 C.P./1 field Tmt. 2C	5000	25	510	7700	20	840	32,900	15	4080	0		0	250	400	6080	2.50 (1.00)	44 (18)	$162Δ (66)
Corn-corn 1 C.P./2 fields Tmts. 5C1, 5C2	5000	25	510	8000	20	880	32,900	15	4080	8110	20	890	250	400	7010	2.50 (1.00)	44 (18)	$115ΔΔ (46)
Alfalfa-corn 1 C.P./2 fields Tmts. 6A, 6C	5000	25	510	8000	20	880	32,900	15	4080	8110	20	890	250	400	7010	2.50 (1.00)	44 (18)	$115ΔΔ (46)
Alfalfa-alfalfa 1 C.P./2 fields Tmts. 7A1, 7A2	5000	25	510	8000	20	880	32,900	15	4080	8110	20	890	250	400	7010	2.50 (1.00)	44 (18)	$115ΔΔ (46)
Alfalfa 1 C.P./1 field Tmt. 4A	5000	25	510	7700	20	840	32,900	15	4080	0		0	250	400	6080	2.50 (1.00)	44 (18)	$162Δ (66)
Alfalfa Dryland Tmt. 3A		---			---			---			---		---	---	0	0	0	0
Alfalfa (early) -corn (late) 1 C.P./2 fields Tmts. 8A, 8C	5000	25	510	8000	20	880	32,900	15	4080	8110	20	890	250	400	7010	2.50 (1.00)	44 (18)	$115ΔΔ (46)

°Well is assumed to be 30.5 m (100 ft) deep.
++Annual costs are figured by means of a capital recovery factor at 9 percent.
+Mainline costs include going into and coming out of ground 3 times plus the cost of an extra pivot pad at $350.
°°Based on approximately 1.25 percent of the cost of a new center pivot.
*An added $2.5/ha (1.00/acre) is assumed to be the average increase in real estate taxes of irrigated land over dry land taxes.
**Land that is irrigable is assumed to be worth about $500/ha ($200/acre) more than otherwise equal dry land that is not irrigated. Added interest is figured at 9 percent of the increase in value.
Δ Based on 52.6 ha (130 acres).
ΔΔ Based on two 52.6 ha (130 acre) tracts.

Table 17. Annual Production Costs for Irrigated and Dryland Fields.

	Corn				Alfalfa			
	Dryland[Δ]		Irrigated		Dryland		Irrigated	
	$/ha	($/acre)	$/ha	($/acre)	$/ha	($/acre)	$/ha	($/acre)
Field operating costs	26.00	(10.50)	32.00	(13.00)	28.00	(11.25)	42.00	(17.00)
Fertilizer	27.00	(11.00)	123.50	(50.00)	30.25	(12.25)	60.50	(24.50)
Weed and insect control	11.00	(4.50)	30.50	(12.50)	0	(0)	0	(0)
Seed	20.00	(8.00)	37.00	(15.00)	8.50	(3.50)	8.50	(3.50)
Irrigation system repairs	0	(0)	5.00	(2.00)	0	(0)	5.00	(2.00)
Crop insurance*	6.00	(2.50)	12.50	(5.00)	0	(0)	0	(0)
6% capital charge on above°	5.00	(2.00)	14.50	(6.00)	3.75	(1.50)	7.00	(2.75)
Subtotal	95.00	(38.50)	255.00	(103.50)	70.50	(28.50)	123.00	(49.75)
Fixed machinery	32.00	(13.00)	39.50	(16.00)	37.00	(15.00)	37.00	(15.00)
Labor[+]	20.00	(8.00)	25.00	(10.00)	32.00	(13.00)	48.00	(19.50)
Miscellaneous overhead	7.50	(3.00)	7.50	(3.00)	7.50	(3.00)	7.50	(3.00)
Total	154.50	(62.50)	327.00	(132.50)	147.00	(59.50)	215.50	(87.25)

*Crop insurance on corn is based on enough insurance at a rate of 4 percent to cover the operating costs. Crop insurance on alfalfa is generally not carried.

°The 6 percent capital charge is based on a 9 percent annual rate for 9 months.

+Labor does not include labor required to move the system.

ΔCosts are based on the management associated with an expected yield of 2500 kg/ha (40 bu/acre).

Table 18. Summary of Costs and Returns for Given Irrigation Management Schemes.*

Management scheme	Electricity costs, $° Ser-vice	Electricity costs, $° Stand-by	Electricity costs, $° Total	Electricity costs, $° $/ha ($/acre)	Annual fixed costs+ $/ha ($/acre)	Annual cost of production, $Δ Field 1	Annual cost of production, $Δ Field 2	Annual cost of production, $Δ Field 1 and field 2	Annual cost of production, $Δ Average cost $/ha ($/acre)	Additional labor costs, $** Total	Additional labor costs, $** $/ha ($/acre)	Total annual costsΔΔ $/ha ($/acre)	Expected gross return, $°° Field 1	Expected gross return, $°° Field 2	Expected gross return, $°° Field 1 and field 2	Expected gross return, $°° Average return $/ha ($/acre)	Return to land and management++ $/ha ($/acre)
Corn Dryland Tmt. 1C	0	0	0	0	0	8,125	---	8,125	154 (62)	0	0	154 (62)	3,250	---	3,250	62 (25)	-92 (-37)
Corn 1 C.P./1 field Tmt. 2C	1090	760	1850	35.20 (14.20)	162 (66)	17,200	---	17,200	327 (132)	0	0	524 (212)	43,300	---	43,300	823 (333)	299 (121)
Corn-corn 1 C.P./2 fields Tmts. 5C1, 5C2	1870	950	2820	26.80 (10.80)	115 (46)	17,200	17,200	34,400	327 (132)	715	6.80 (2.75)	476 (192)	35,100	35,100	70,200	667 (270)	191 (78)
Alfalfa-corn 1 C.P./2 fields Tmts. 6A, 6C	1960	950	2910	27.60 (11.20)	115 (46)	11,300	17,200	28,500	271 (110)	715	6.80 (2.75)	420 (170)	37,300	35,100	72,400	688 (278)	268 (108)
Alfalfa-alfalfa 1 C.P./2 fields Tmts. 7A1, 7A2	2100	950	3050	29.00 (11.70)	115 (46)	11,300	11,300	22,600	215 (87)	810	7.70 (3.10)	367 (148)	37,300	37,300	74,600	709 (287)	342 (139)
Alfalfa 1 C.P./1 field Tmt. 4A	1330	760	2090	39.70 (16.10)	162 (66)	11,300	---	11,300	215 (87)	0	0	417 (169)	37,300	---	37,300	709 (287)	292 (118)
Alfalfa Dryland Tmt. 3A	0	0	0	0	0	7,700	---	7,700	146 (59)	0	0	146 (59)	19,800	---	19,800	375 (152)	229 (93)
Alfalfa (early) -corn (late) 1 C.P./2 fields Tmts. 8A, 8C	1560	950	2510	23.90 (9.60)	115 (46)	11,300	17,200	28,500	271 (110)	65	0.60 (0.25)	410 (166)	29,400	43,300	72,700	690 (279)	280 (113)

*Slight differences in comparisons of the values expressed in terms of hectares and acres are due to rounding.
°Based on hours of pumping and power requirements listed in Table 15 along with the electrical rates listed in Table 14.
+Fixed costs listed in Table 16.
ΔBased on 130 acres per field and the production cost data listed in Table 17.
**Based on the hours needed to move the machine (Table 15) at $3.25 per hour.
ΔΔEstimated costs do not include any costs due to interest on the land investment or real estate taxes other than the added taxes of irrigated land over dry land.
°°Based on 130 acres per field, the yield data from Table 15 and the price data from Table 14.
++Return is expected gross return minus total annual costs, which do not include land costs.

The return to land and management column of Table 18 basically shows the type of information, at one commodity price level, that may be used to evaluate the differences between certain irrigation management schemes. The return to land and management values will be quite susceptible to changing price levels, however, the differences between the returns of the various management schemes will probably not be affected as much by the changing price levels as the actual returns. For example, if the price of electricity should increase by one-half, the return to land and management would be $281/ha ($114/acre) for the corn (one center pivot per one field) management scheme and $178/ha ($72/acre) for the corn-corn (one center pivot per two fields) management scheme. The average reduction in return would be $15/ha ($6/acre). The original difference between the two schemes was $108/ha ($44/acre) while it would now be $103/ha ($42/acre). By changing a price level, the return to land and management changed by an average of $15/ha ($6/acre) while the difference between two management schemes only changed by $5/ha ($2/acre).

Data that could be used to estimate annual costs for management schemes similar to the schemes investigated in this research were also presented by Stegman (1975). Stegman investigated the use of one center pivot on up to three fields. If one uses Stegman's estimates of seasonal irrigation and the number of system moves in an analysis similar to the one presented in Table 18, another set of annual costs is derived (Appendix E). Stegman's work, which was done on a deeper soil, indicated that the yields were not reduced by using a center pivot machine on more than one field. Thus, any differences in annual costs would also represent the relative gain in return between the respective management schemes. Using Stegman's raw data, the annual cost reduction from using one center pivot on one field compared to using one center pivot on two fields of the same crop was approximately $50.00/ha ($20.30/acre) for both corn and alfalfa. The values obtained in this research were approximately $48/ha ($19.50/acre) for corn and $50/ha ($20.50/acre) for alfalfa. As can be seen, the differences in annual costs based on Stegman's data are extremely close to the differences based on the data from this research.

The returns to land and management thus far have been calculated on the basis of only one commodity price level. Since the commodity price levels tend to fluctuate more than the price levels for equipment, power and labor, the returns to land and management were calculated at additional commodity price levels. The return to land and management at the various commodity prices are presented in Table 19. The price ranges vary from $78.60/1000 kg to $117.90/1000 kg ($2.00/bu to $3.00/bu) for corn and from $44/1000 kg to $66/1000 kg ($40/ton to $60/ton) for alfalfa.

Figures 14, 15 and 16 graphically indicate the variations in return for the different management schemes. The figures are based on the values listed in Table 19. When only corn is grown, Figure 14 shows that the greatest return to land and management, for the commodity prices considered, is obtained by using a management scheme where one center pivot machine is used to irrigate one tract of land. The reduction in annual costs per unit area, due to the smaller initial investment

Table 19. Return to Land and Management at Given Commodity Price Levels.+

Management scheme	Return to Land and Management,° $/ha ($/acre)								
	Corn 78.60/1000kg ($2.00/bu) Alfalfa 44/1000kg ($40/ton)	Corn 78.60/1000kg ($2.00/bu) Alfalfa 55/1000kg ($50/ton)	Corn 78.60/1000kg ($2.00/bu) Alfalfa 66/1000kg ($60/ton)	Corn 98.20/1000kg ($2.50/bu) Alfalfa 44/1000kg ($40/ton)	Corn 98.20/1000kg ($2.50/bu) Alfalfa 55/1000kg ($50/ton)	Corn 98.20/1000kg ($2.50/bu) Alfalfa 66/1000kg ($60/ton)	Corn 117.90/1000kg ($3.00/bu) Alfalfa 44/1000kg ($40/ton)	Corn 117.90/1000kg ($3.00/bu) Alfalfa 55/1000kg ($50/ton)	Corn 117.90/1000kg ($3.00/bu) Alfalfa 66/1000kg ($60/ton)
Corn Dryland Tmt. 1C	-104 (-42)	-104 (-42)	-104 (-42)	-92 (-37)	-92 (-37)	-92 (-37)	-79 (-32)	-79 (-32)	-79 (-32)
Corn 1 C.P./1 field Tmt. 2C	133 (54)	133 (54)	133 (54)	299 (121)	299 (121)	299 (121)	462 (187)	462 (187)	462 (187)
Corn-corn 1 C.P./2 fields Tmts. 5C1, 5C2	58 (24)	58 (24)	58 (24)	191 (78)	191 (78)	191 (78)	325 (132)	325 (132)	325 (132)
Alfalfa-corn 1 C.P./2 fields Tmts. 6A, 6C	130 (53)	201 (81)	272 (110)	197 (80)	268 (108)	339 (137)	264 (107)	335 (136)	405 (164)
Alfalfa-alfalfa 1 C.P./2 fields Tmts. 7A1, 7A2	199 (81)	342 (139)	483 (196)	199 (81)	342 (139)	483 (196)	199 (81)	342 (139)	483 (196)
Alfalfa 1 C.P./1 field Tmt. 4A	149 (60)	292 (118)	433 (175)	149 (60)	292 (118)	433 (175)	149 (60)	292 (118)	433 (175)
Alfalfa Dryland Tmt. 3A	153 (62)	229 (93)	303 (123)	153 (62)	229 (93)	303 (123)	153 (62)	229 (93)	303 (123)
Alfalfa (early) -corn (late) 1 C.P./2 fields Tmts. 8A, 8C	142 (57)	198 (80)	254 (103)	225 (91)	280 (113)	336 (136)	307 (124)	362 (146)	418 (169)

+Slight differences in comparisons of the values expressed in terms of hectares and acres are due to rounding.
°The alfalfa prices listed in the heading are for hay at 12% moisture. Dry matter prices for alfalfa are $50.90, $63.70 and $76.40/1000kg ($46.30, $57.90 and $69.40/ton).

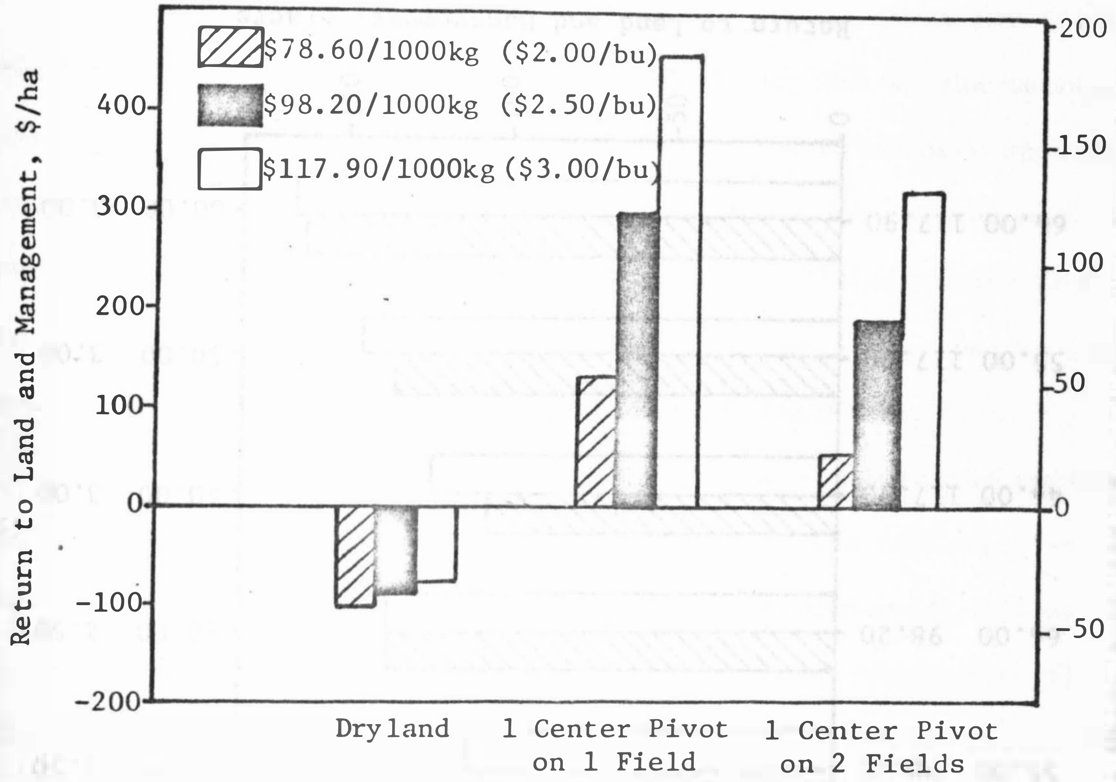

Figure 14. Returns for Management Schemes Where Only Corn Is Grown.

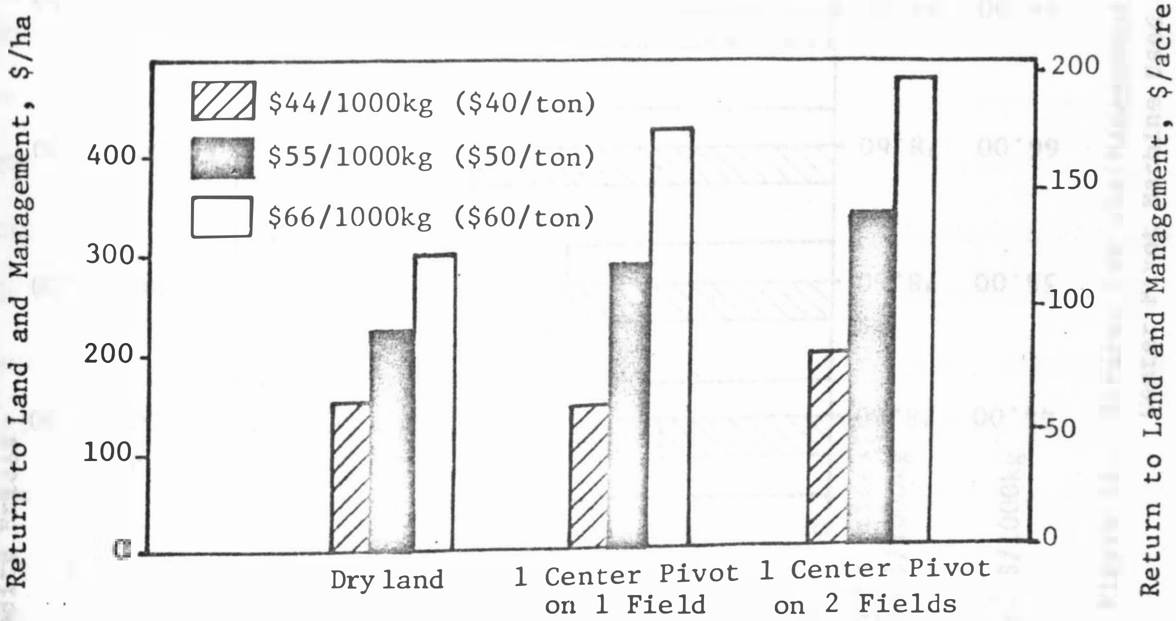

Figure 15. Returns for Management Schemes Where Only Alfalfa Is Grown.

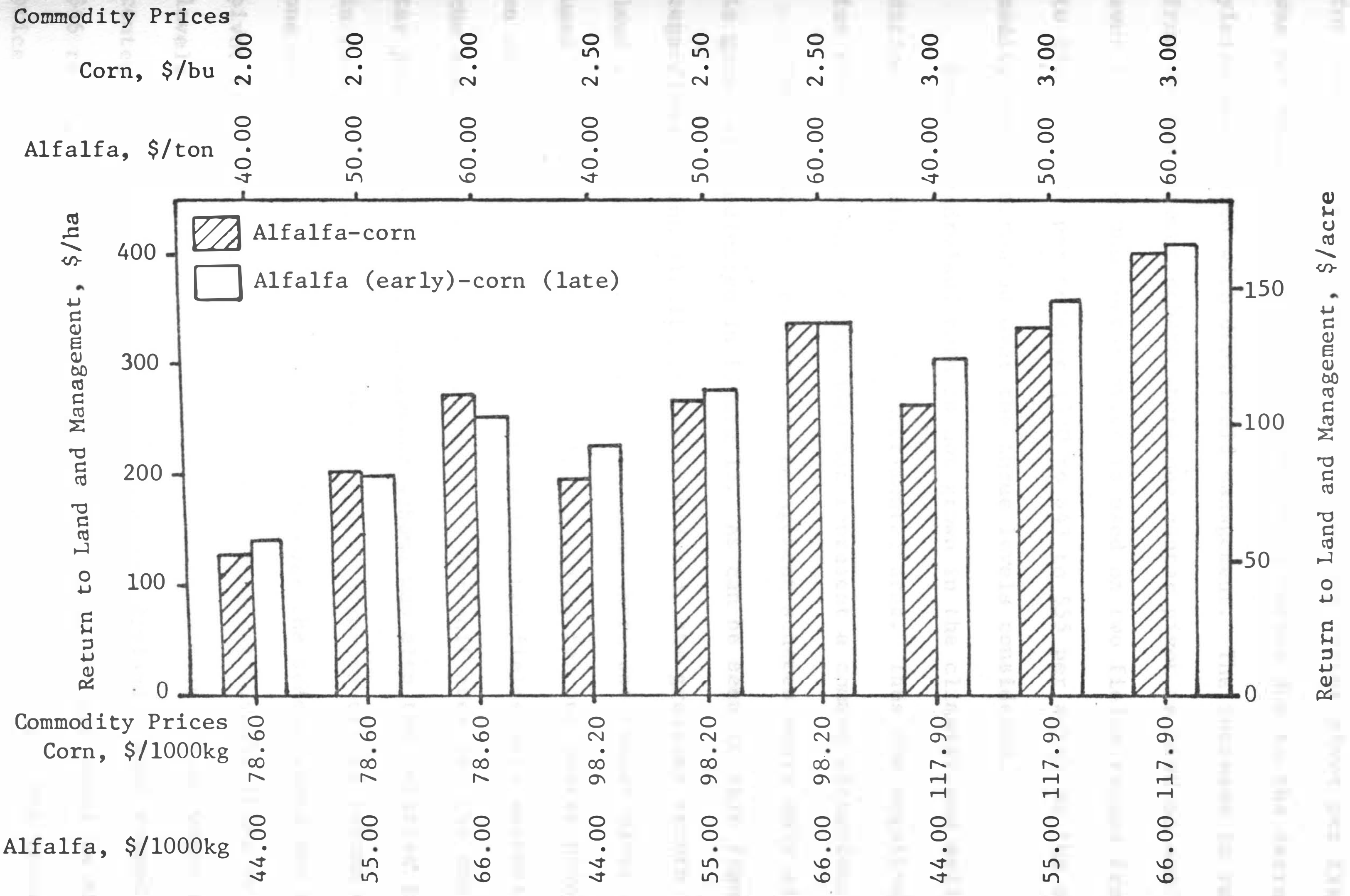

Figure 16. Returns for the Management Schemes Where Both Alfalfa and Corn Are Grown (One Center Pivot Machine Used on Two Fields).

for one center pivot per two fields over one center pivot per field, was not enough to offset the reduction in return due to the decreased yields associated with dual field management. The increase in return from the management scheme where one center pivot is used on one field over that where one center pivot is used on two fields ranged from $75 to $108 to $137 per hectare ($30 to $43 to $55 per acre) as the commodity price increased over the three levels considered.

Generally dryland corn is not grown in the climatic and soil conditions associated with the experimental area. Thus the negative return for this management scheme does not represent a common situation.

The various returns for the management schemes where only alfalfa is grown are indicated in Figure 15. As can be seen in this figure, regardless of the alfalfa prices considered, the greatest return to land and management comes from the scheme where one center pivot is used on two fields. Since the alfalfa yields for one center pivot used on one field and one center pivot used on two fields were essentially the same, the reduction in annual costs per unit area for the one center pivot on two fields management scheme was also the relative increase in return for that scheme. The increase in return of the scheme where one center pivot is used on two fields over the scheme where one center pivot is used on one field was $50/ha ($21/acre) for all three price levels. The increase in return from the management scheme where one center pivot is used on two fields over the dryland scheme ranged from $46 to $113 to $180 per hectare ($19 to $46 to $73 per acre) as the price level increased over the three levels considered. The increase in return from using one center pivot on one field over dryland would be \$50/ha (\$21/acre) less than the increases presented above.

For example, at the middle price level the increase in return from one center pivot on one field over dryland would be \$113/ha (\$46/acre) minus \$50/ha (\$21/acre) or \$63/ha (\$25/acre). The return from the dryland scheme is about equal to the return from the one center pivot on one field scheme at the lowest alfalfa price level.

The two schemes where both corn and alfalfa are grown are compared in Figure 16. It can be seen that there is generally not much difference between the two schemes. Where there is a low alfalfa commodity price, the highest returns are achieved with the alfalfa (early)-corn (late) scheme. This scheme is slightly biased towards corn production since the system spends most of the growing season on the corn. When the price of corn is low and the price of alfalfa is high the alfalfa-corn scheme gives slightly higher returns. At the higher prices for corn, the alfalfa (early)-corn (late) scheme gives a slightly higher return than the alfalfa-corn scheme.

In the cost and return analyses a capacity of 3.8 m^3/min (1000 gpm) was assumed for both the corn (early)-alfalfa (late) and the alfalfa-corn management schemes. This capacity was such that 2.5 cm (1 in) of water could be applied every 3.5 days although the alfalfa (early)-corn (late) scheme only assumed an application frequency of 4 days. The 4 day frequency could be attained with a capacity of 3.0 m^3/min (800 gpm). The higher capacity was assumed for this scheme since an irrigator wishing to grow both corn and alfalfa would probably want the option of using either management scheme. The only differences in costs associated with the higher capacity assumption are in the pump, motor and panel and the differences amount to less than \$0.50/ha/year (\$0.20/acre/year).

Thus far the optimal returns have been compared in Figures 14, 15 and 16 for management options where alfalfa is grown, where corn is grown or where both corn and alfalfa are grown. Figure 17 compares the returns among these three management options. It was assumed in these comparisons that an irrigator has two adjacent quarters that will be managed under the optimal scheme for a given option. At the price levels considered, when the price of corn is low any management option where alfalfa is grown gives higher returns than the option where only corn is grown. The management option where only alfalfa is grown gives the highest return. When the price of corn is approximately \$98/1000 kg (\$2.50/bu) the return from a management option where just corn is grown only exceeds the return from the option where just alfalfa is grown when the price of alfalfa is low, or approximately \$44/1000 kg (\$40/ton). As the price of alfalfa increases the return from the combination of a quarter of alfalfa and a quarter of corn also exceeds the return of the management option where only corn is grown. When the price of corn is high, or in the neighborhood of \$118/1000 kg (\$3.00/bu), the return from the management option where only corn is grown exceeds the return from any of the other options except the option where only alfalfa is grown and the price of alfalfa is \$66/1000 kg (\$66/ton) or more. In general the management option where only alfalfa is grown gives the

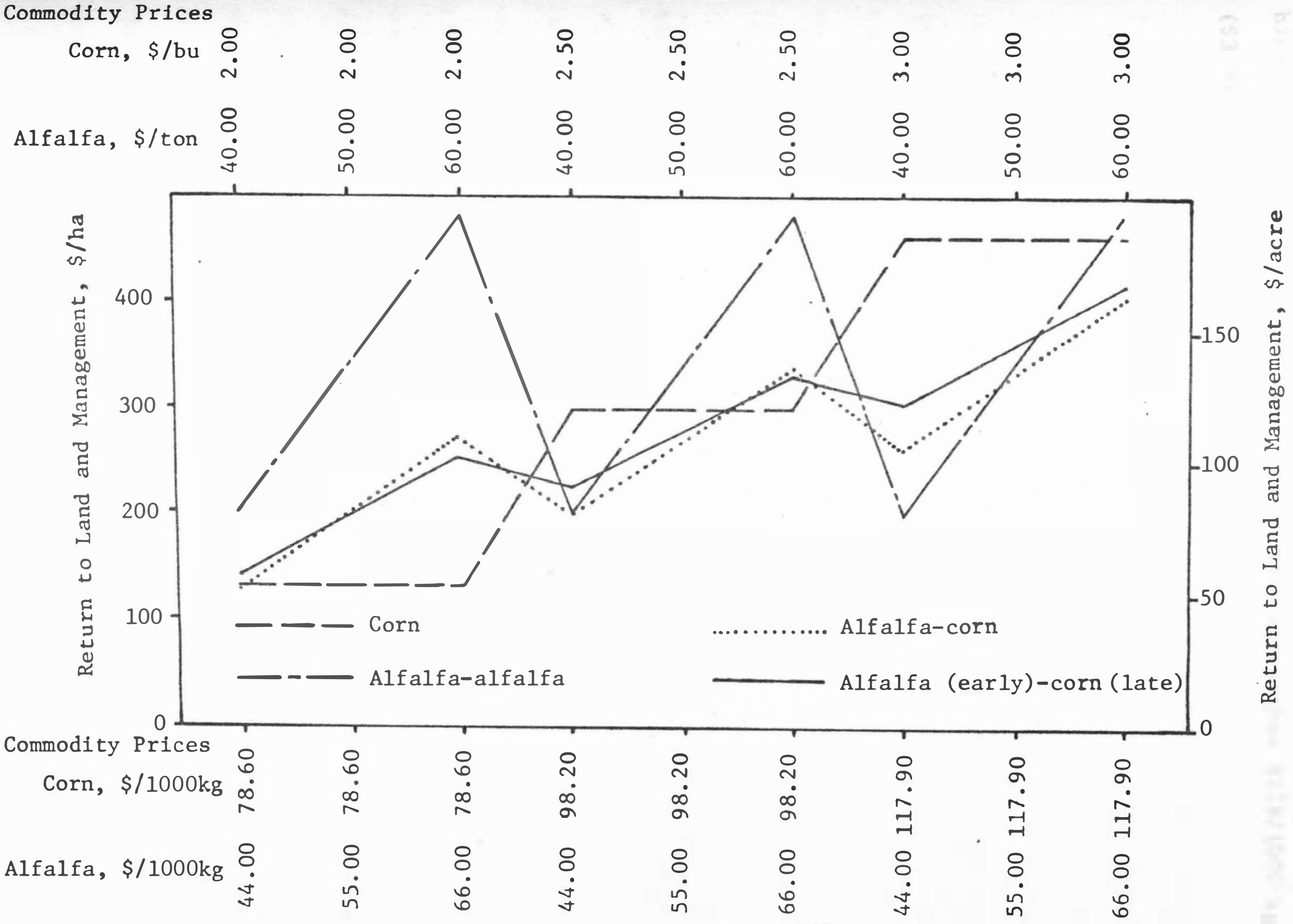

Figure 17. Comparison of the Maximum Returns from the Options Where Alfalfa, Corn or a Combination of Alfalfa and Corn Is Grown.

highest return except when the price of corn approaches \$118/1000 kg (\$3.00/bu).

SUMMARY AND CONCLUSIONS

Some South Dakota irrigators have been using their center pivot irrigation machines to irrigate more than one field during the growing season. At the present time, however, there is very limited information regarding the economics of such a procedure when practiced in the South Dakota climatic region and when practiced under shallow, drought susceptible soil conditions. In order to provide such information a study was undertaken to obtain a production function from which yield estimates for specific irrigation management schemes could be made and used in economic analyses of the schemes.

The schemes considered in the experiment involved three main options. The options consisted of growing corn, alfalfa, or a combination of corn and alfalfa. For the corn and alfalfa options, the irrigation management schemes considered were the use of one center pivot machine on one field and the use of one center pivot machine on two adjacent fields. Two schemes were investigated for the management option where one center pivot machine was used to irrigate a corn field and an alfalfa field. In one scheme the center pivot machine was moved periodically between the two fields for the entire season. The second scheme was one where the center pivot machine was used to irrigate the alfalfa field early in the season and then the corn field for the rest of the season. The irrigated management schemes were also compared to dryland management schemes.

The schemes were simulated by means of a plot study at the Agricultural Engineering Farm near Brookings, South Dakota. The 12.2 m by

12.2 m (40 ft by 40 ft) plots were independently irrigated to simulate the irrigation depths and frequencies that a field would receive from a center pivot machine used in connection with any of the given schemes. The soil in the plot area ranged from a loam to a silty clay loam with a depth of approximately 46 cm (18 in). The drought susceptible soil had available moisture storage of approximately 6.1 cm (2.4 in). Soil moisture was monitored to help explain some of the effects that the individual schemes had on yields. Yields gathered from the plots in 1973, 1974 and 1975 were used to derive production functions from which yield estimates for the individual schemes were made. The yield estimates were used to estimate gross returns for the management schemes.

Once the field data had been gathered, economic analyses which consisted of estimating annual costs and annual returns for each management scheme were conducted. The annual costs estimates were based on current equipment and electrical costs, current crop production costs and estimated factors, such as seasonal irrigation depth, associated with the individual schemes. The gross returns were based on the field plot yields and on several levels of commodity prices. The returns to land and management, which consisted of gross annual returns minus annual costs, provided economic comparisons of the schemes considered in the study.

The following conclusions were made from the field investigation. The conclusions were based on simulated irrigation management schemes under shallow, drought susceptible soil conditions.

1. Corn and alfalfa yields from the dryland management schemes

were lower than the yields of any of the irrigated management schemes.

2. Corn yields were significantly reduced when one center pivot machine was used to irrigate two fields of corn.
3. There were no differences in corn yields caused by irrigation timing effects associated with the movement of a center pivot machine between two fields.
4. There were no significant differences between alfalfa yields from the management schemes where one center pivot machine was used to irrigate one field and where one center pivot machine was used to irrigate two fields.
5. Alfalfa yields were higher than dryland yields but lower than the yields from the fields that were irrigated the entire season for the management scheme where an alfalfa field is irrigated until early July at which time the system is moved to a corn field. The corn yields associated with this scheme were about the same as the yields from a field where one center pivot machine is used to irrigate one field for the entire season.

The following conclusions were made from the economic analyses. The conclusions are based on field plot yields and on the price levels presented in the text.

1. One center pivot machine used to irrigate one corn field was the corn management scheme which gave the highest return to land and management for the commodity price levels considered.

2. One center pivot machine used to irrigate two alfalfa fields was the alfalfa management scheme which gave the highest return to land and management for the commodity price levels considered.
3. The differences in return to land and management between the two management schemes where both corn and alfalfa were grown were slight and varied somewhat depending on the commodity prices.
4. Of the three basic management options considered, alfalfa, corn and a combination of alfalfa and corn, the one that gave the highest return to land and management varied depending on commodity prices.

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APPENDIXES

APPENDIX A

PRICE INFORMATION

PRICE INFORMATION*

Electrical

Table A1. Electrical Rate Schedules.

Source	Yearly stand by	Rate/ kw-hr	Extra charge for electric center pivot	Cable from hook-up point to center pivot
A	\$12.70/measured kw (\$9.50/measured hp)	\$0.0190	\$250	\$3.28/m (\$1.00/ft)
B	\$10.70/measured kw (\$8.00/measured hp)	\$0.0192°	---	---
C	\$11.70/connected kw (\$8.75/connected hp)	\$0.0160°	---	---
D	\$13.40/measured kw (\$10.00/measured hp)	\$0.0150+	---	---
E	---	---	---	\$3.28/m (\$1.00/ft)
F	---	---	---	\$3.28/m (\$1.00/ft)

°The first 134 kw-hr/kw (100 kw-hr/hp) used are included in the yearly stand by charge.

+The first 268 kw-hr/measured kw (200 kw-hr/measured hp) have a rate of \$0.05/kw-hr. From 268 kw-hr/measured kw (200 kw-hr/measured hp) to 670 kw-hr/measured kw (500 kw-hr/measured hp) there is a rate of \$0.035/kw-hr. After 670 kw-hr/measured kw (500 kw-hr/measured hp) the rate is \$0.015/kw-hr.

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*Approximate price information was gathered from the following rural electric cooperatives: Cam-Wall Electric, Selby, South Dakota; Turner-Hutchinson, Marion, South Dakota; H and D Electric, Clear Lake, South Dakota and Sioux Valley Empire Electric, Colman, South Dakota. Approximate prices were obtained from the following irrigation equipment suppliers: Getting Industries, Sioux Falls, South Dakota; James Basin Builders, Aberdeen, South Dakota and Morris Irrigation, Ft. Pierre, South Dakota. The data was gathered through telephone conversations during April, 1976. Information was also obtained from Darrel Pahl of the South Dakota State University Extension Service.

Well and Casing

Estimated total cost for well and casing:

$164/m ($50/ft) Sources E and G

Pump, Motor and Panel

The pumping rates and the pressures simulated in the experiment require motors in the 56 kw (75 hp) to 74.6 kw (100 hp) range:

Table A2. Estimated Pump, Motor and Panel Costs.

	56 kw (75 hp)				74.6 kw (100 hp)			
Source	Pump	Motor	Panel	Hook-up	Pump	Motor	Panel	Hook-up
E	$4000	$2750	$ 950	---	$4000	$3050	$ 950	---
F	---	---	$1000	---	---	---	$1000	---
H	---	$1750	$ 990	$500	---	$2350	$ 990	$500

Center Pivot Machine

Prices are estimated total prices for a typical towable 10 tower electric machine, complete with erection and freight included:

$35,300 Source E

$31,000 Source F

$32,300 Source H

Mainline

Approximate price of 3.15 cm (8 in) PVC mainline installed:

$9.51/m ($2.90/ft) Source E

$7.55/m ($2.30/ft) Source F

$8.20/m ($2.50/ft) Source H

Approximate price to come out of or go into the ground with the mainline:

$300 Source E

$375 Source F

$200 Source H

Pivot Pad

Approximate added cost for an extra pivot pad:

$300 Source E

$550 Source F

$250 Source H

APPENDIX B

SOIL MOISTURE DEPLETION CURVES

SYMBOLS USED IN

APPENDIX B

– Calculated moisture content

⊙ – Measured moisture content

– Irrigation

– Rainfall

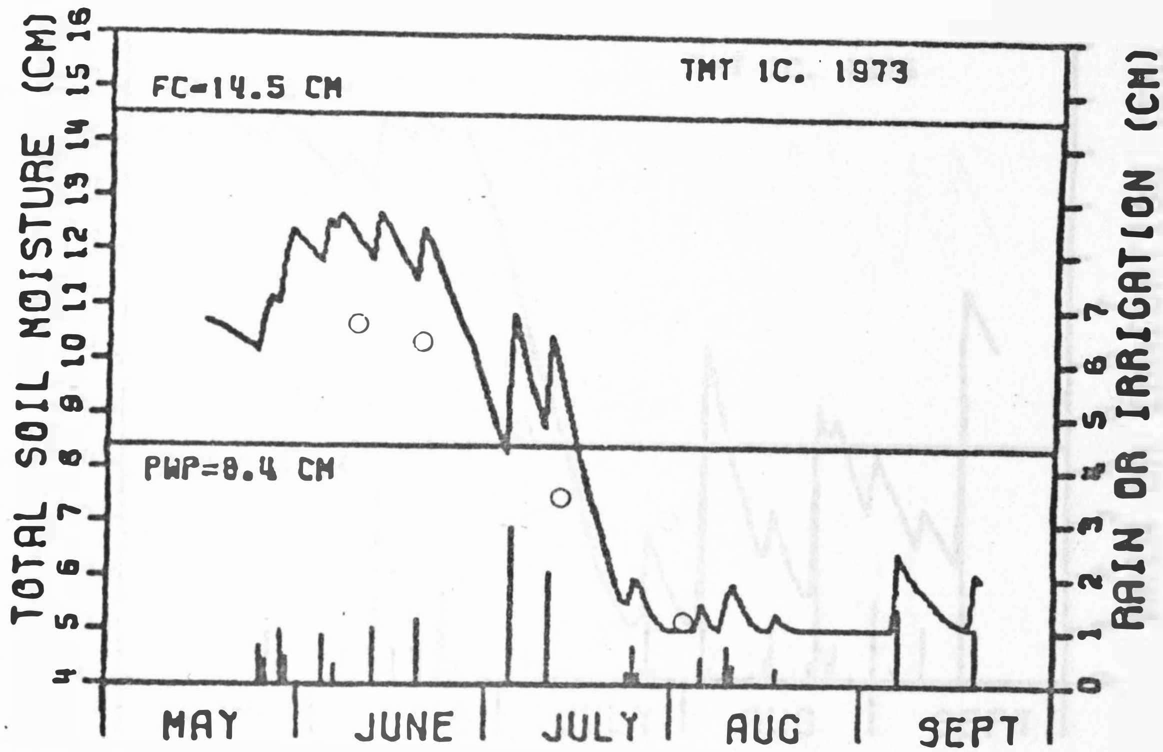

Figure B1. Soil Moisture Depletion Curves for Treatment 1C, Dryland.

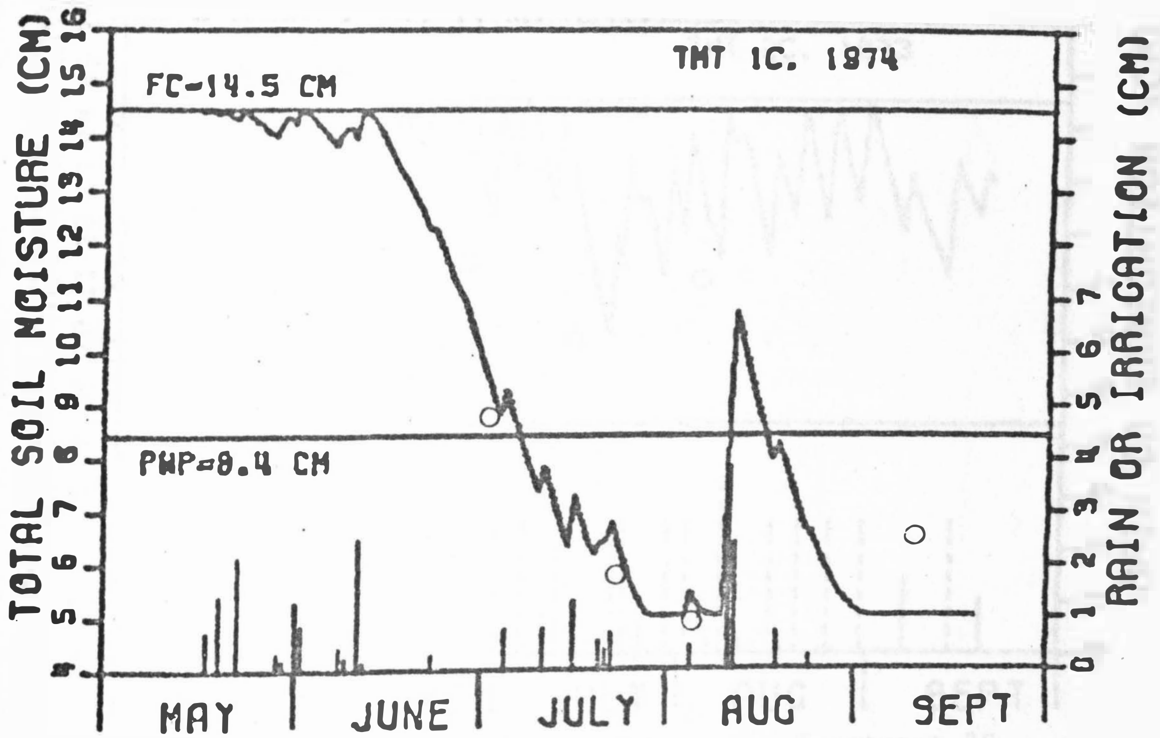

Figure B1. Soil Moisture Depletion Curves for Treatment 1C, Dryland (continued).

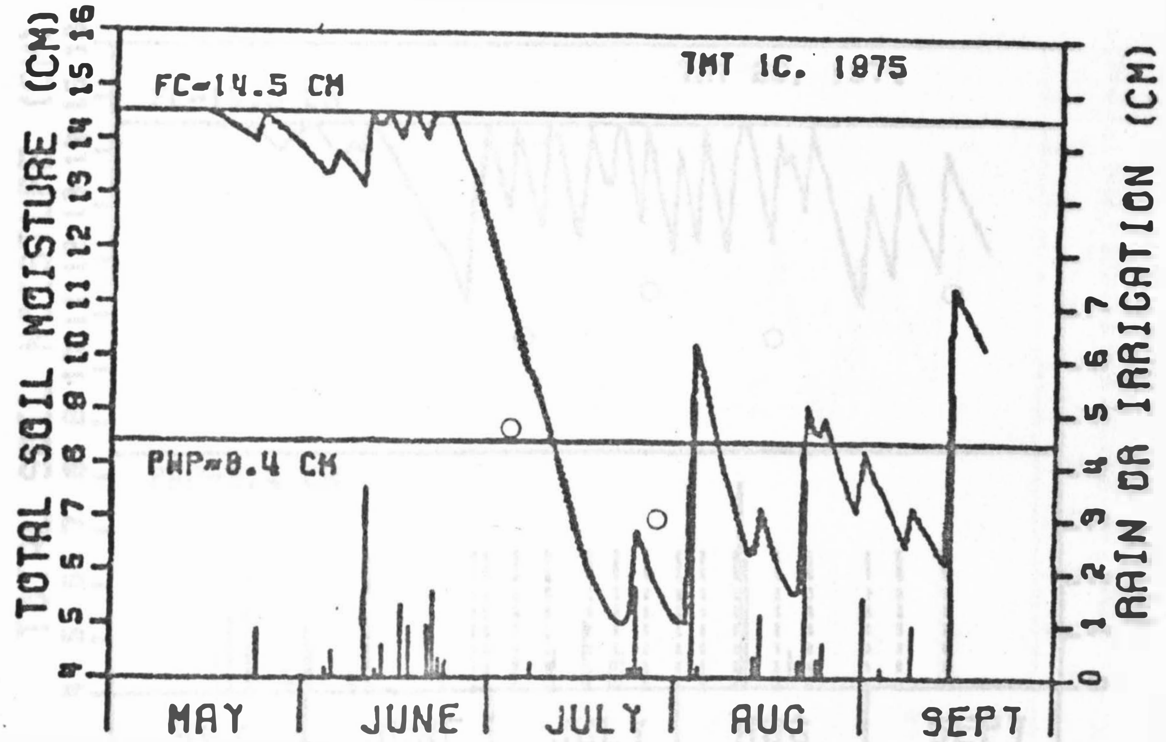

Figure B1. Soil Moisture Depletion Curves for Treatment 1C, Dryland (continued).

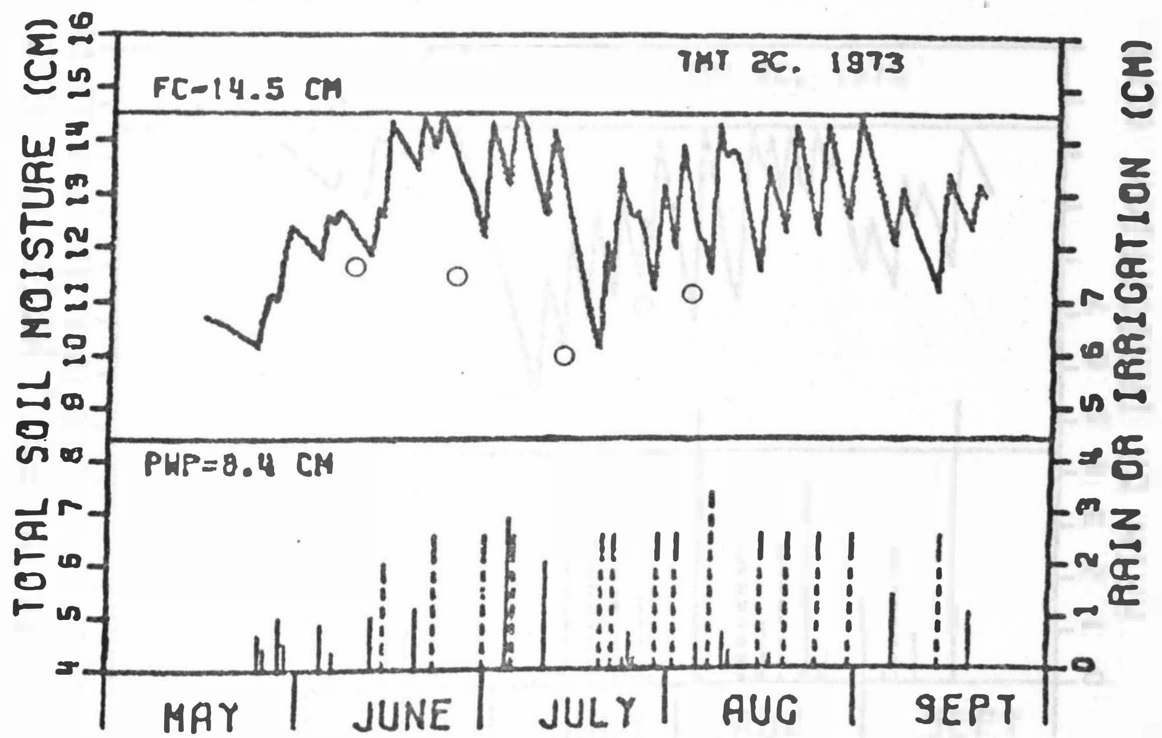

Figure B2. Soil Moisture Depletion Curves for Treatment 2C, 2.5 cm/4 days.

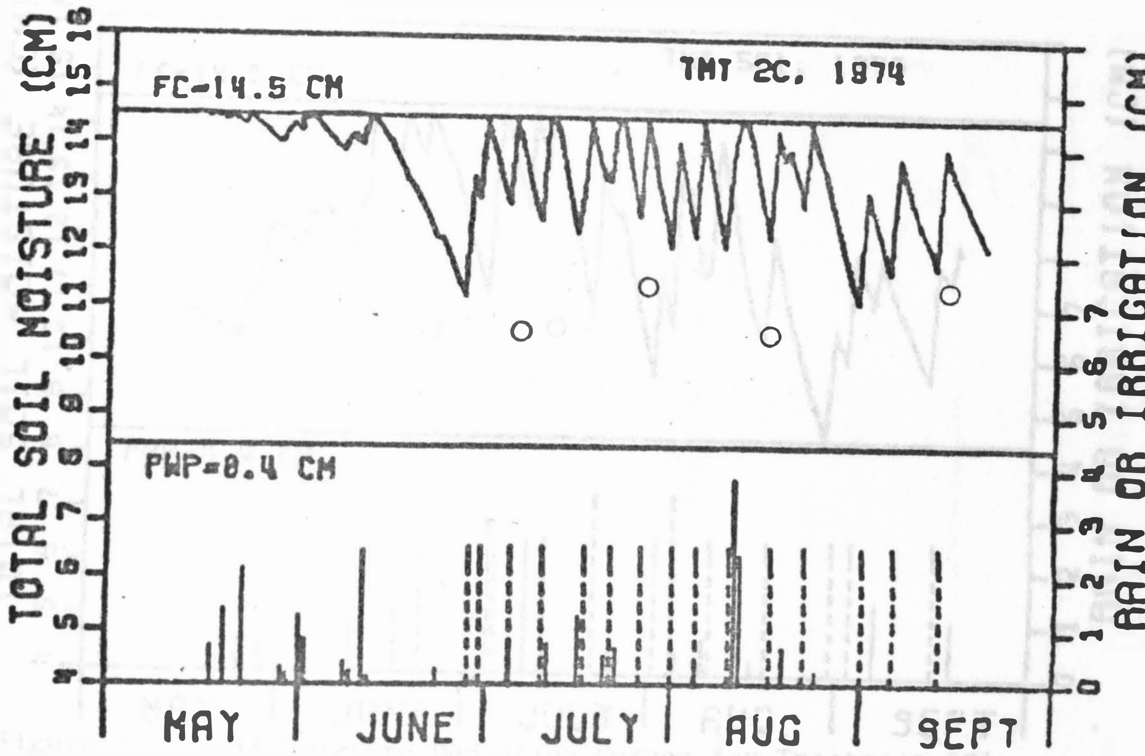

Figure B2. Soil Moisture Depletion Curves for Treatment 2C, 2.5 cm/4 days (continued).

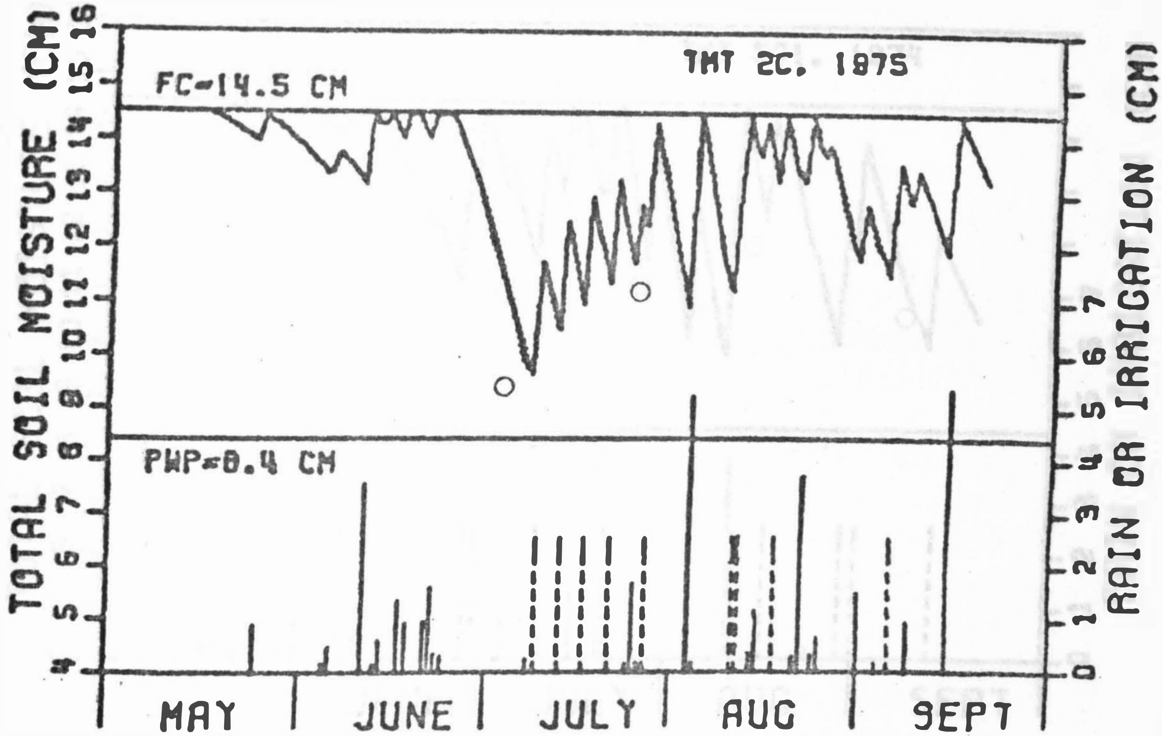

Figure B2. Soil Moisture Depletion Curves for Treatment 2C, 2.5 cm/4 days (continued).

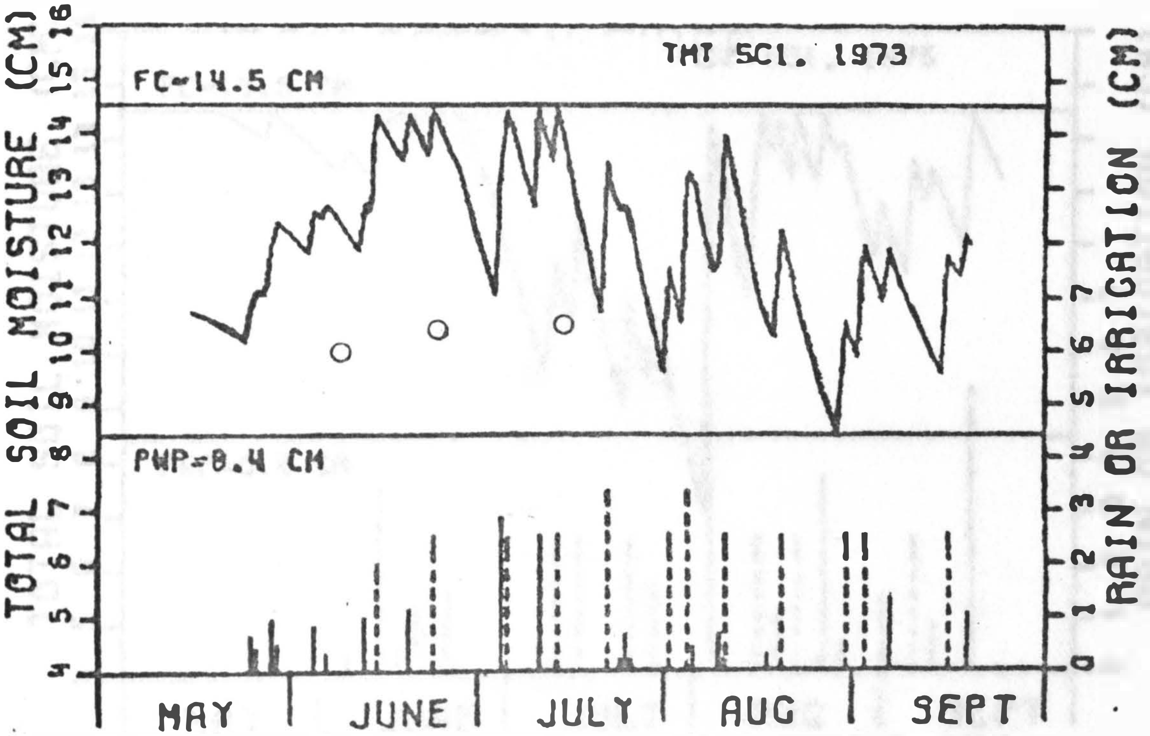

Figure B3. Soil Moisture Depletion Curves for Treatment 5C1, 2.5 cm/7 days.

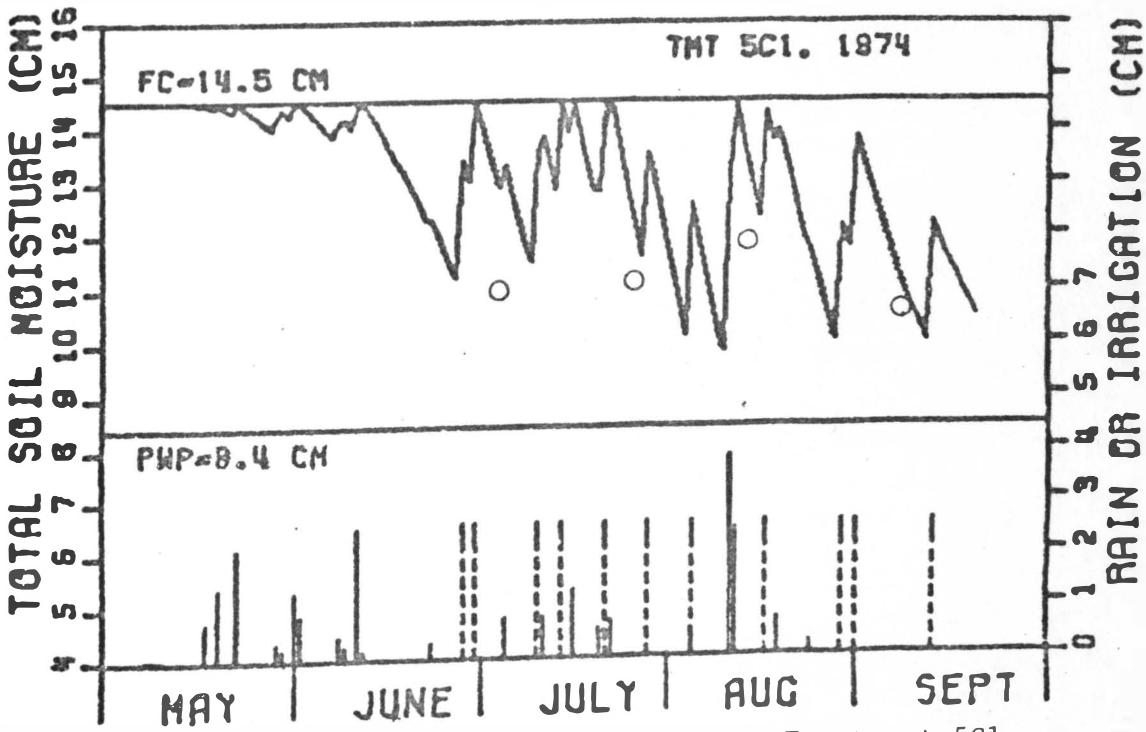

Figure B3. Soil Moisture Depletion Curves for Treatment 5C1, 2.5 cm/7 days (continued).

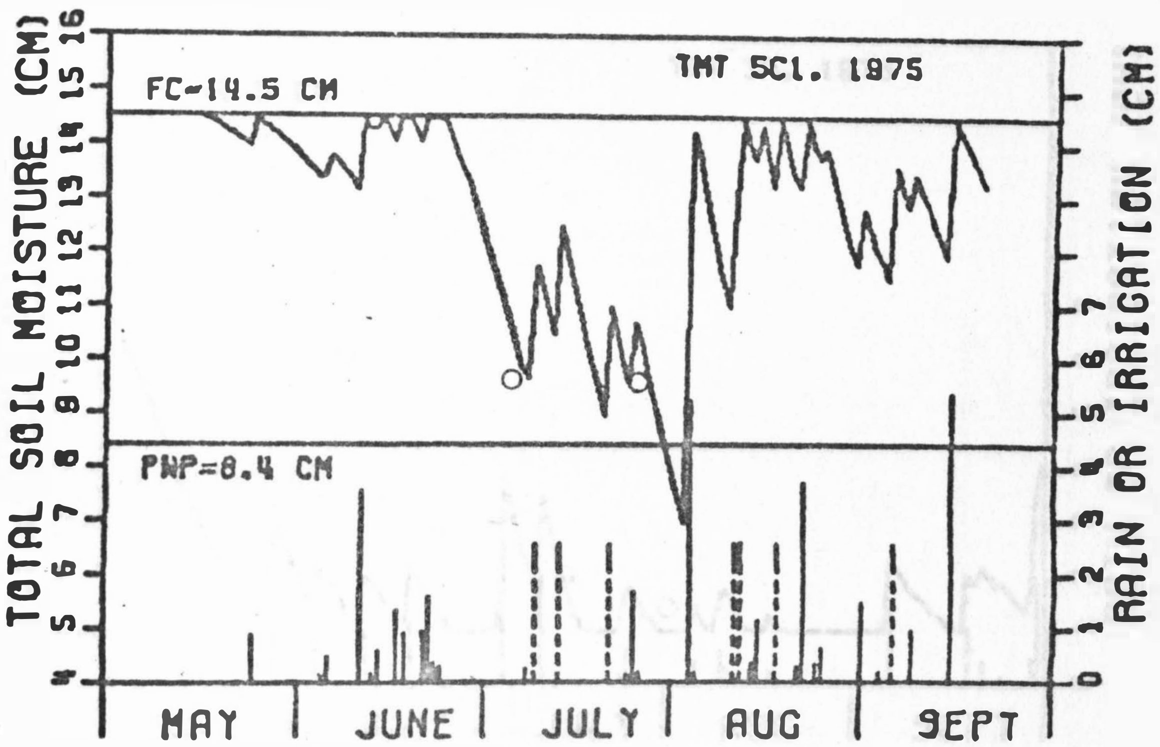

Figure B3. Soil Moisture Depletion Curves for Treatment 5C1, 2.5 cm/7 days (continued).

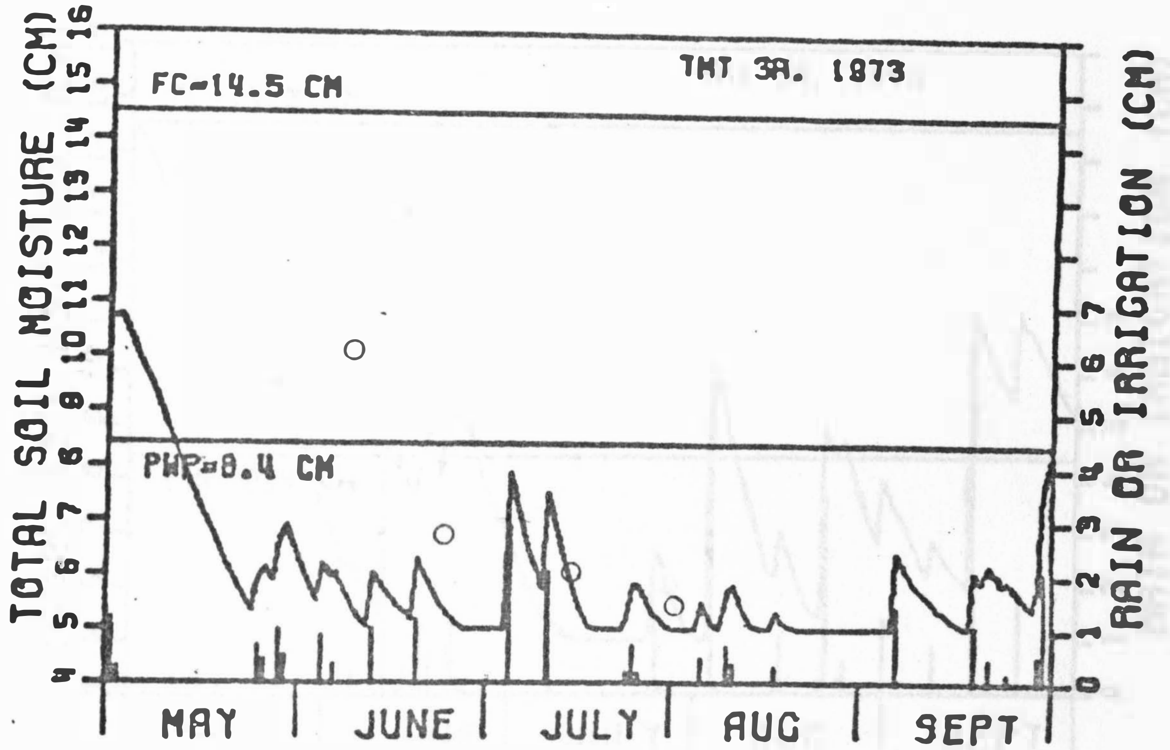

Figure B4. Soil Moisture Depletion Curves for Treatment 3A, Dryland.

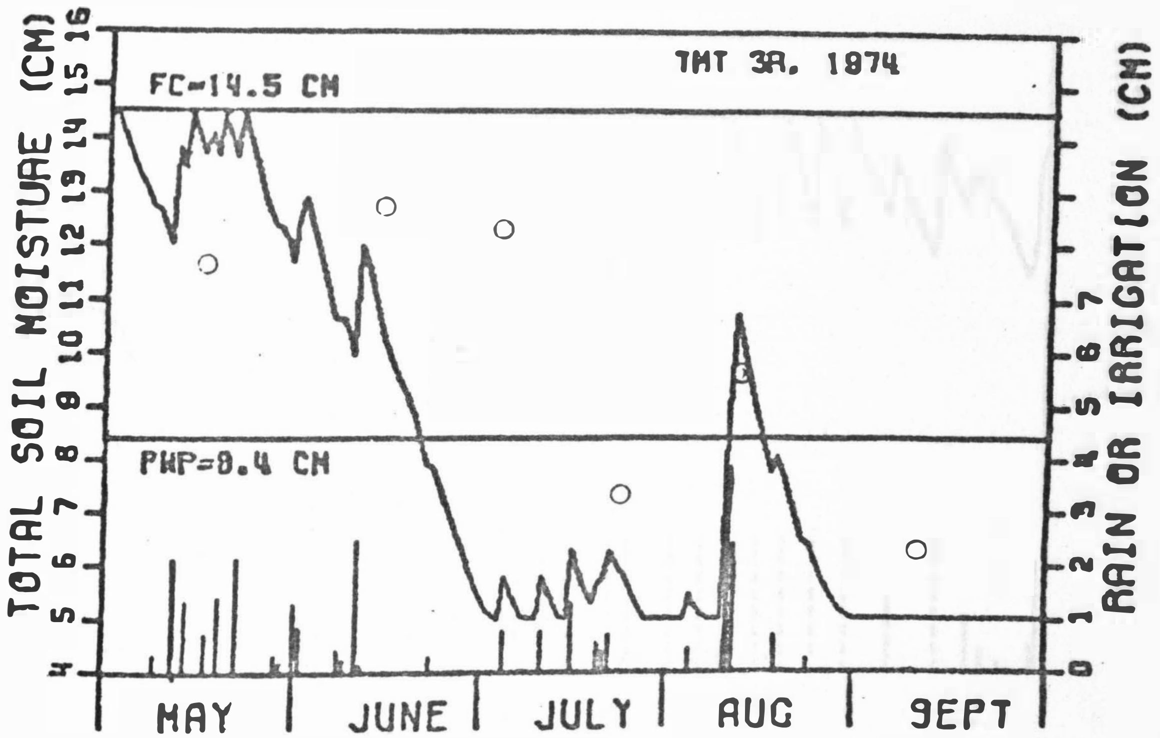

Figure B4. Soil Moisture Depletion Curves for Treatment 3A, Dryland (continued).

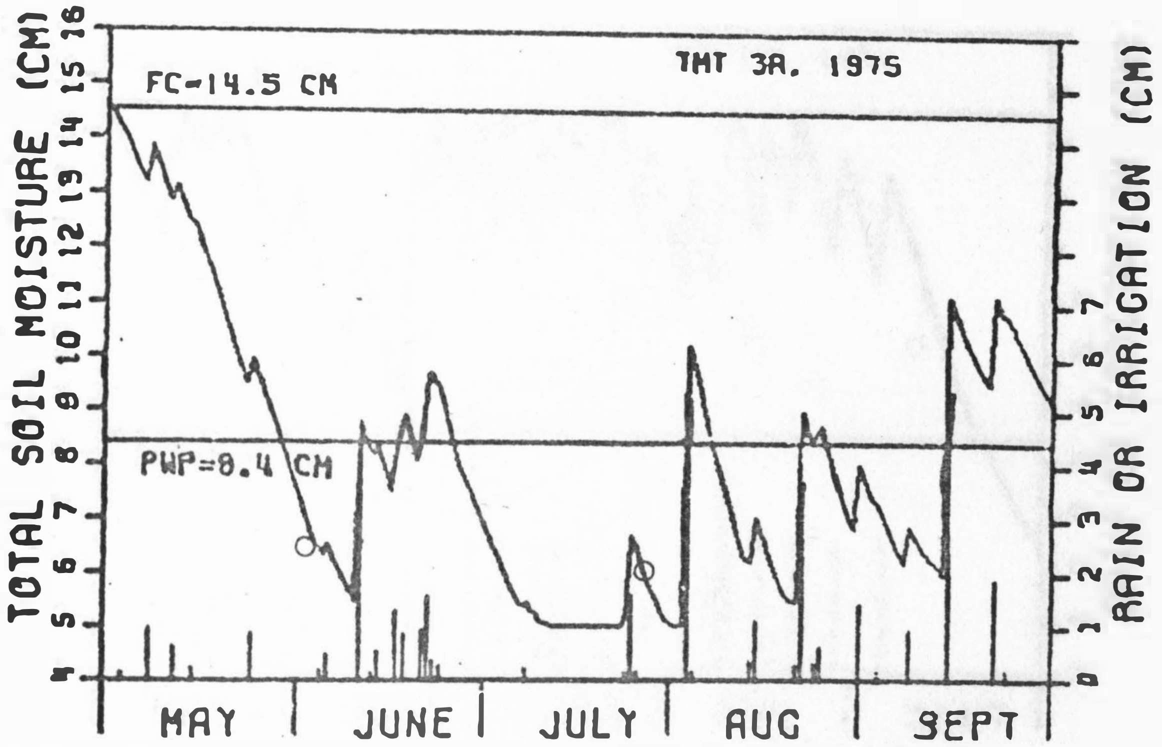

Figure B4. Soil Moisture Depletion Curves for Treatment 3A, Dryland (continued).

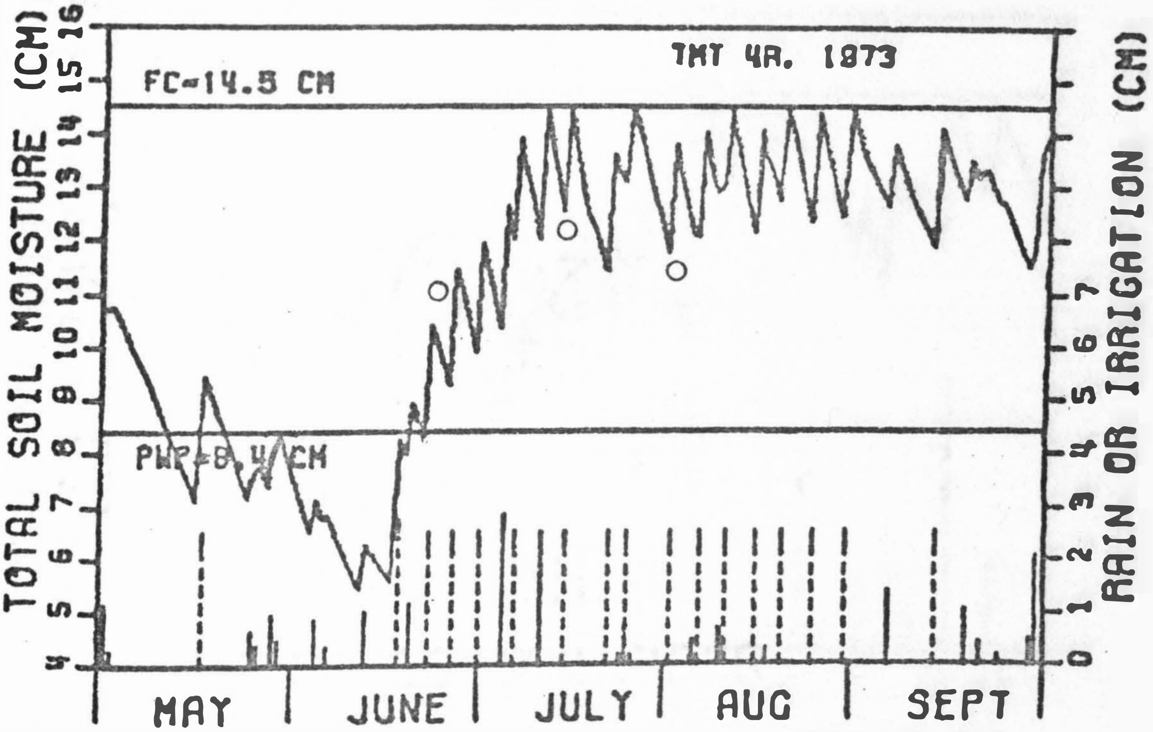

Figure B5. Soil Moisture Depletion Curves for Treatment 4A, 2.5 cm/4 days.

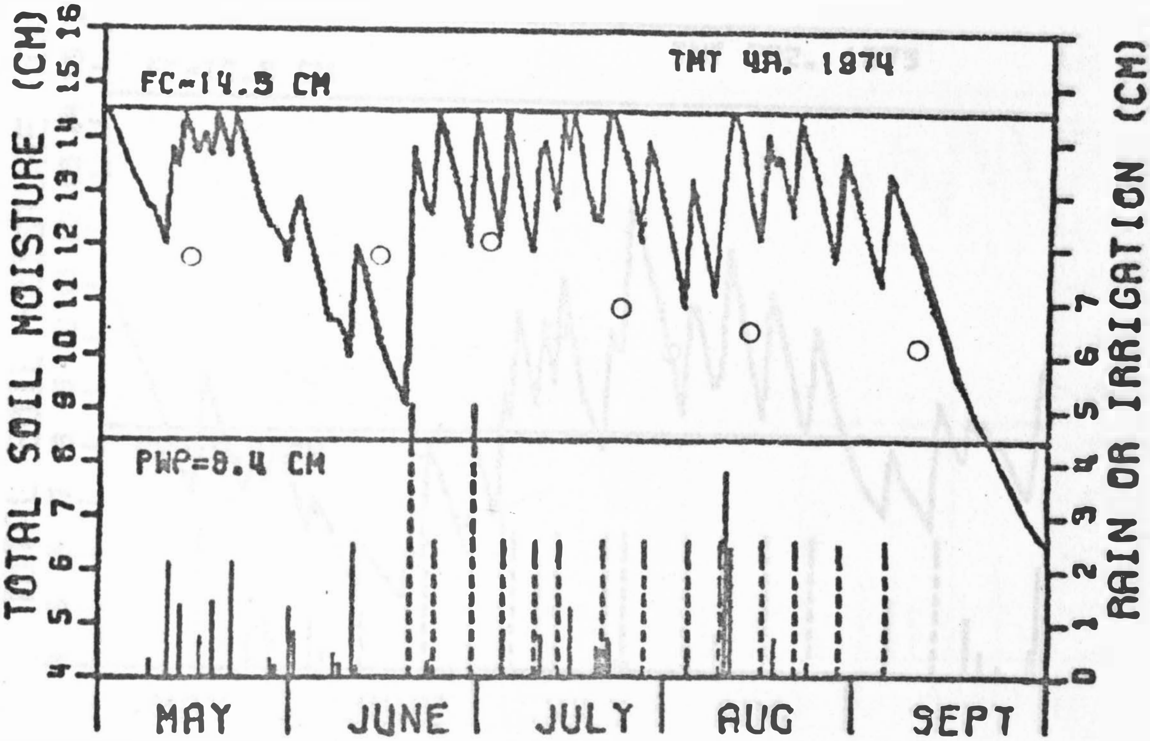

Figure B5. Soil Moisture Depletion Curves for Treatment 4A, 2.5 cm/4 days (continued).

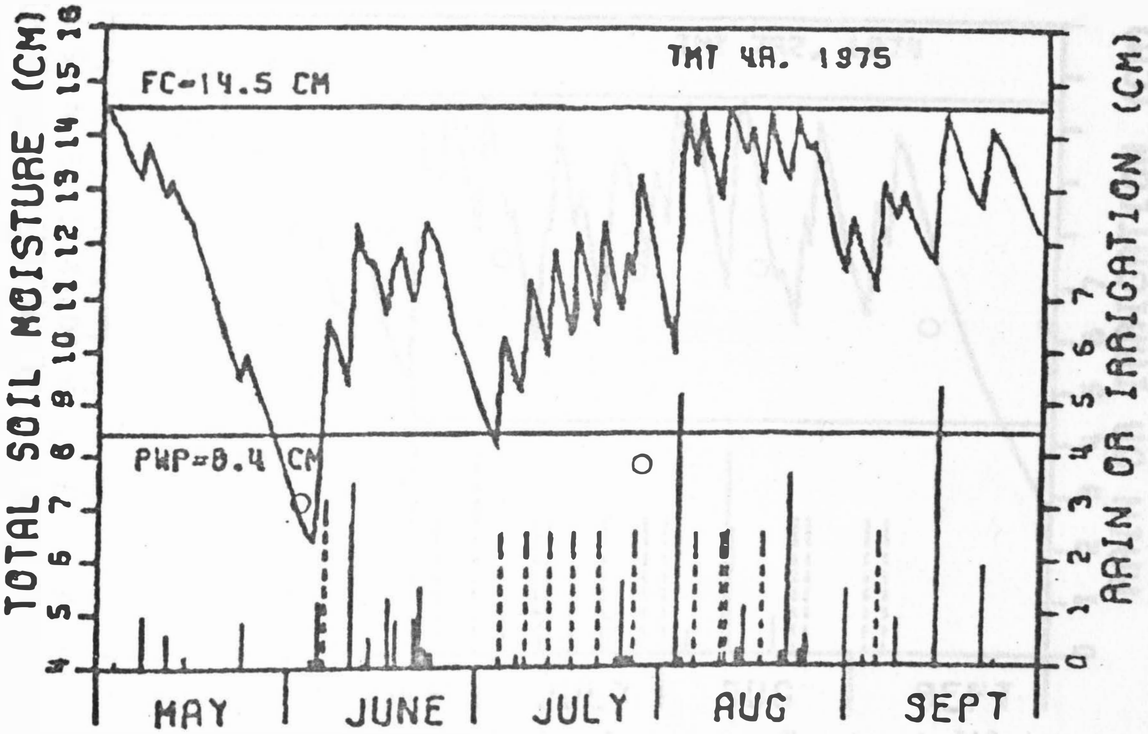

Figure B5. Soil Moisture Depletion Curves for Treatment 4A, 2.5 cm/4 days (continued).

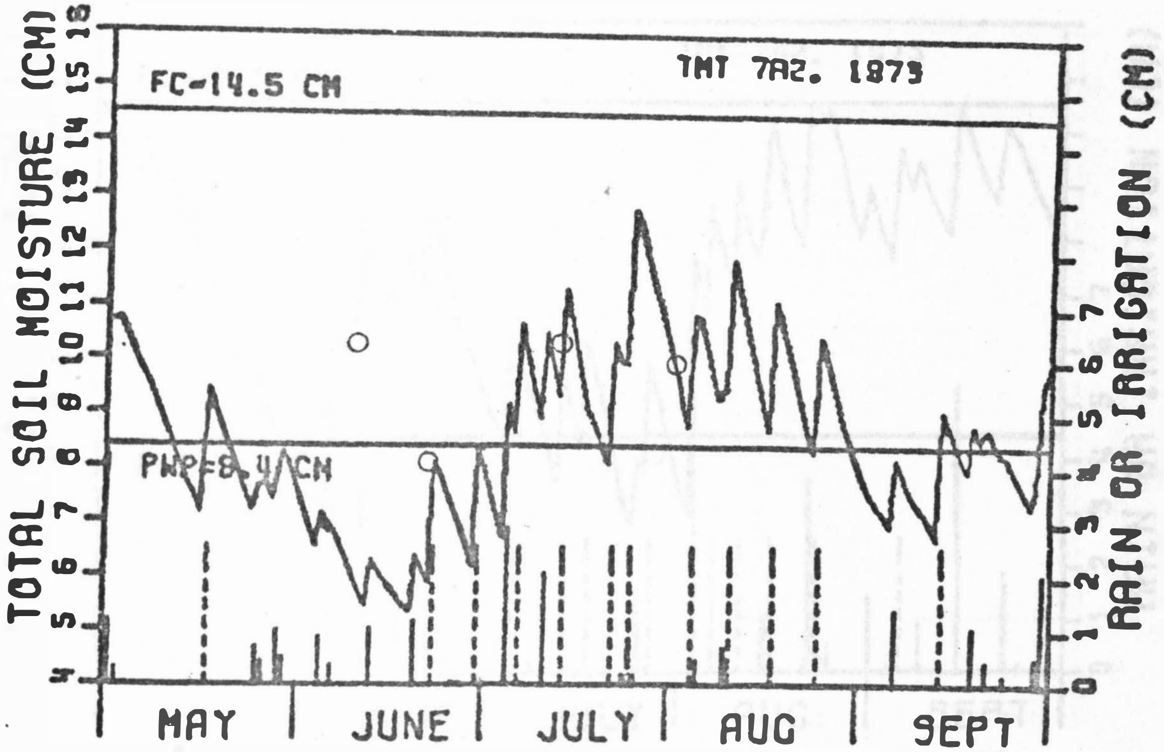

Figure B6. Soil Moisture Depletion Curves for Treatment 7A2, 2.5 cm/7 days.

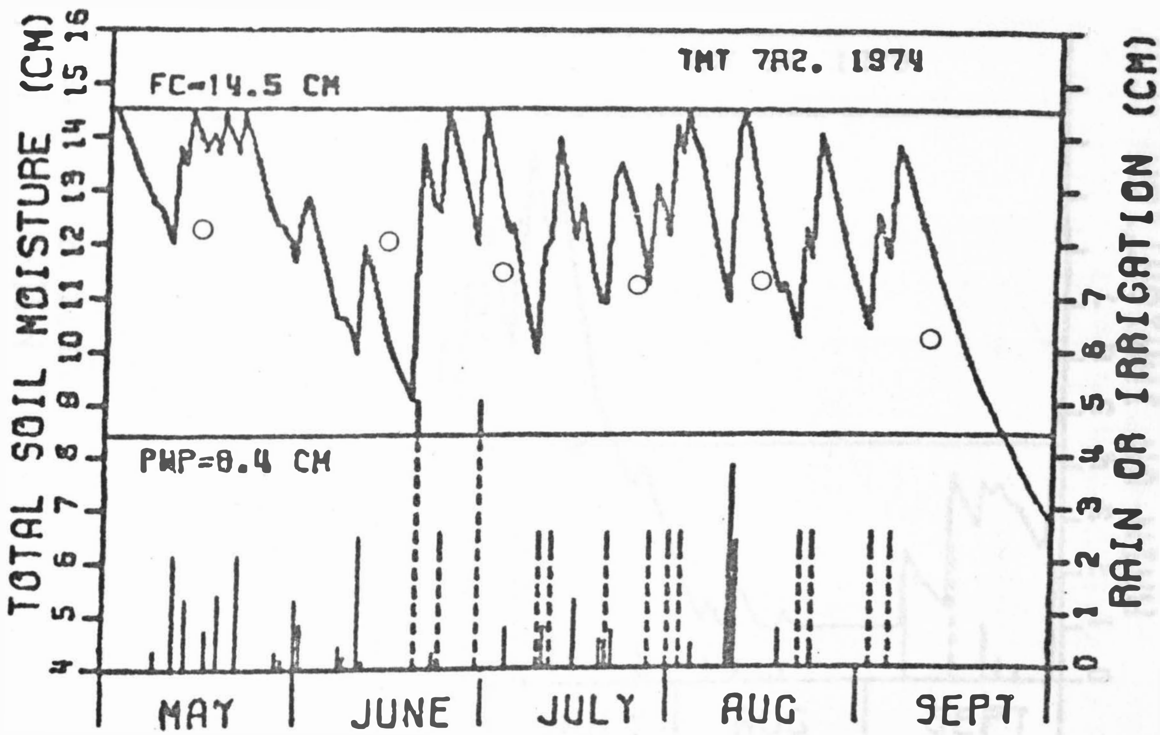

Figure B6. Soil Moisture Depletion Curves for Treatment 7A2, 2.5 cm/7 days (continued).

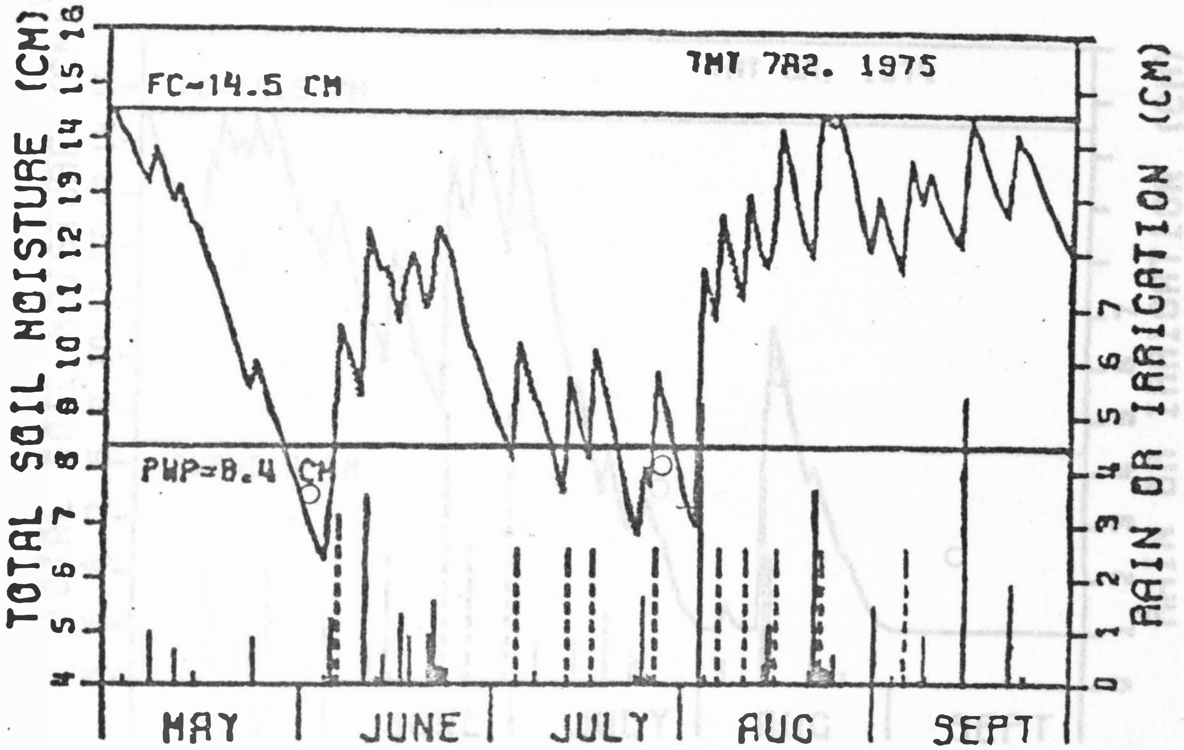

Figure B6. Soil Moisture Depletion Curves for Treatment 7A2, 2.5 cm/7 days (continued).

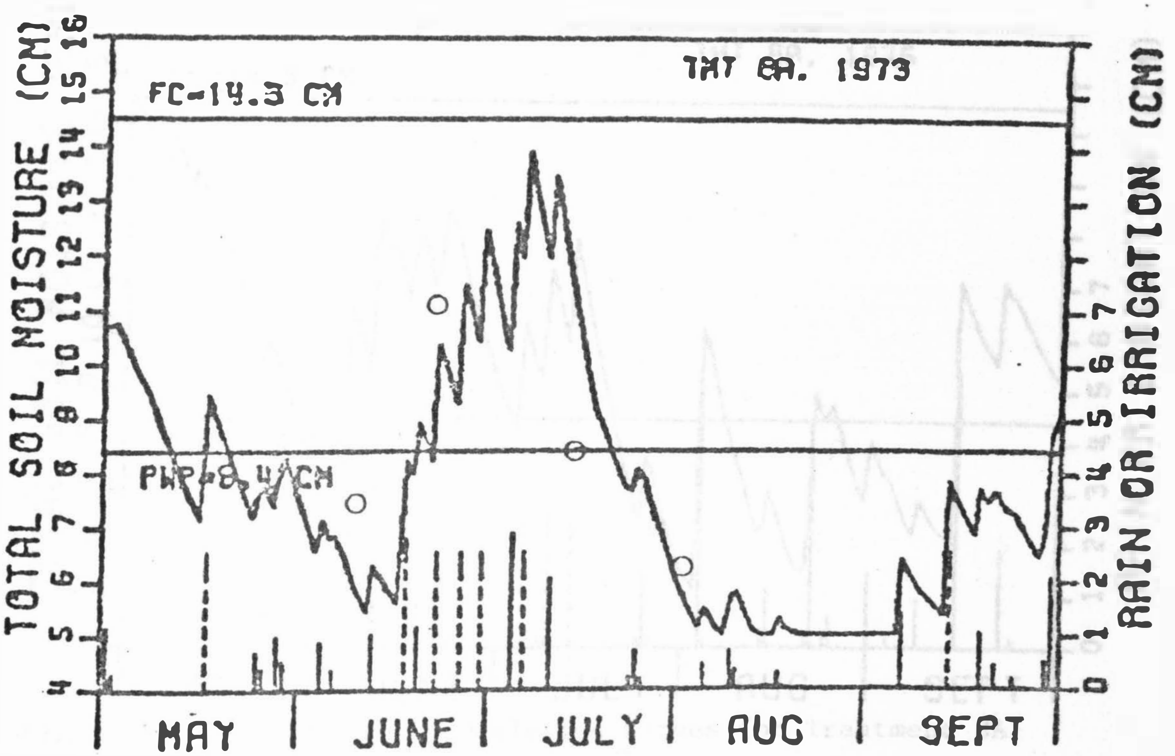

Figure B7. Soil Moisture Depletion Curves for Treatment 8A, Alfalfa Early.

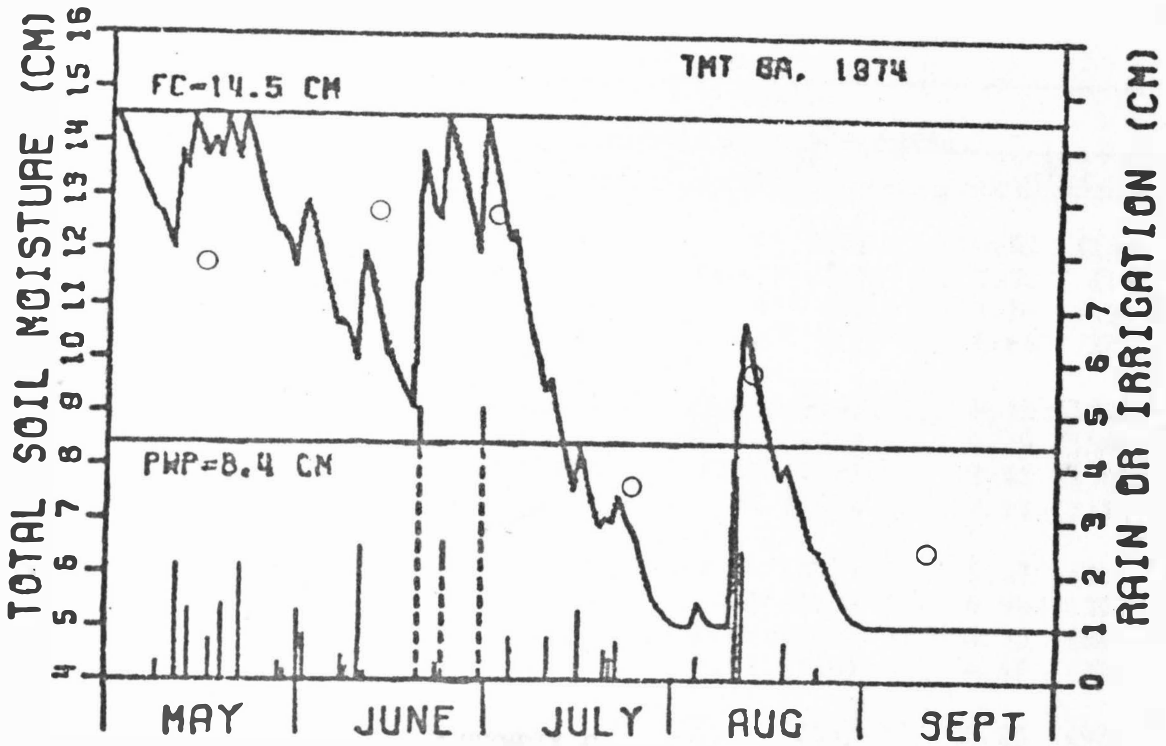

Figure B7. Soil Moisture Depletion Curves for Treatment 8A, Alfalfa Early (continued).

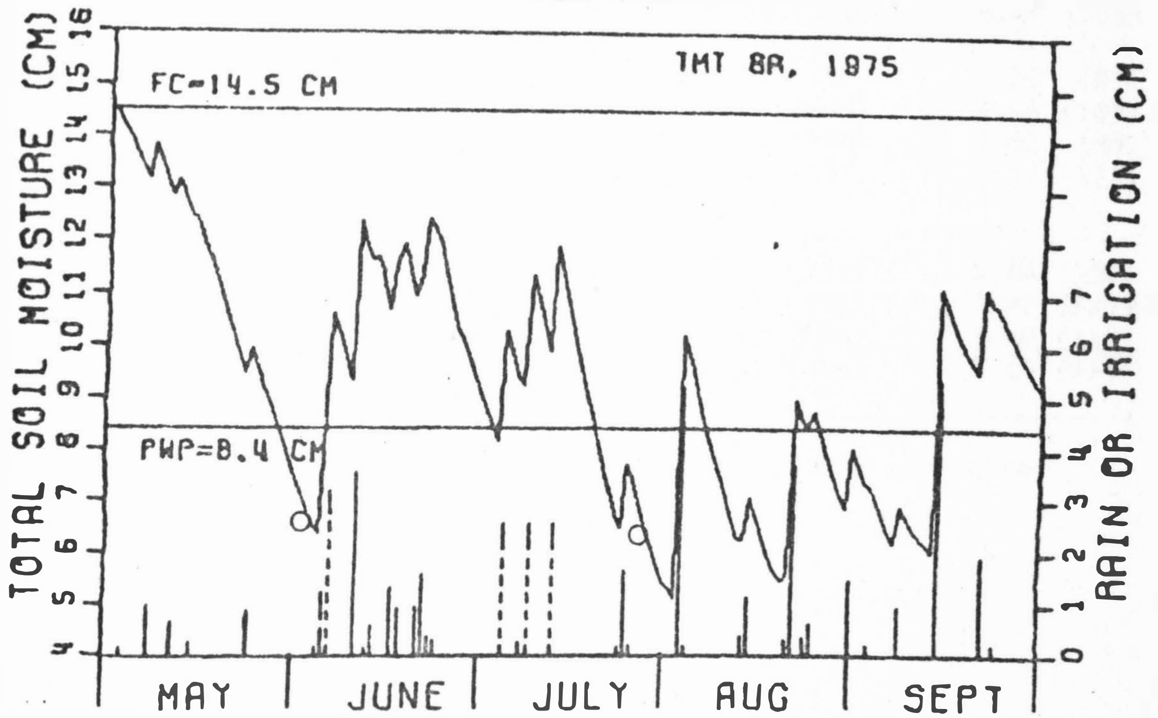

Figure B7. Soil Moisture Depletion Curves for Treatment 8A, Alfalfa Early (continued).

APPENDIX C

INDIVIDUAL PLOT YIELDS

Table C1. Individual Corn Plot Yields.

Treatment	Plot number	Yield* 1,000 kg/ha (bu/acre) 1973	1974	1975
1C	2	0 (0)	0 (0)	0.82 (13)
	4	0.90 (14)	0.43 (6)	0.50 (8)
	16	0.97 (15)	0 (0)	2.70 (43)
	18	0 (0)	0 (0)	1.64 (26)
2C	7	8.78 (140)	7.15 (114)	8.53 (136)
	9	7.66 (122)	5.96 (95)	9.79 (156)
	10	9.60 (153)	7.47 (119)	9.41 (150)
	20	9.60 (153)	7.84 (125)	7.91 (126)
5C1	12	7.53 (120)	7.34 (117)	5.27 (84)
	13	8.35 (133)	7.72 (123)	6.90 (110)
	17	7.91 (126)	6.59 (105)	4.33 (69)
	24	9.16 (146)	7.91 (126)	4.46 (71)
5C2	3	8.22 (131)	6.46 (103)	6.15 (98)
	6	8.91 (142)	6.65 (106)	5.40 (86)
	15	8.60 (137)	7.72 (123)	7.40 (118)
	23	5.46 (87)	6.34 (101)	6.46 (103)
6C	1	7.28 (116)	5.08 (81)	5.52 (88)
	5	9.22 (147)	6.84 (109)	6.46 (103)
	19	6.02 (96)	5.52 (88)	5.02 (80)
	22	7.22 (115)	6.34 (101)	7.22 (115)
8C	8	10.40 (165)	7.40 (118)	9.66 (154)
	11	10.70 (171)	7.59 (121)	7.97 (127)
	14	9.48 (151)	6.90 (110)	7.40 (118)
	21	9.16 (146)	7.91 (126)	7.15 (114)

*Yields are expressed in terms of grain at 15 percent moisture.

Table C2. Individual Alfalfa Plot Yields.

Treatment	Plot number	Yield* 1973, 1000 kg/ha (tons/acre)				Yield* 1974, 1000 kg/ha (tons/acre)				Yield* 1975, 1000 kg/ha (tons/acre)			
		Cutting 1	Cutting 2	Cutting 3	Total	Cutting 1	Cutting 2	Cutting 3	Total	Cutting 1	Cutting 2	Cutting 3	Total
3A	29	4.35 (1.94)	0.60 (0.27)	0 (0)	4.95 (2.21)	4.84 (2.16)	0 (0)	1.12 (0.50)	5.96 (2.66)	4.75 (2.12)	0.20 (0.09)	1.97 (0.88)	6.92 (3.09)
	36	3.76 (1.68)	1.26 (0.56)	0 (0)	5.02 (2.24)	3.68 (1.64)	1.55 (0.69)	0.49 (0.22)	5.71 (2.55)	5.60 (2.50)	0.63 (0.28)	1.90 (0.85)	8.14 (3.63)
	40	4.10 (1.83)	0.52 (0.23)	0 (0)	4.62 (2.06)	4.66 (2.08)	0 (0)	0.09 (0.04)	4.75 (2.12)	4.93 (2.20)	0.45 (0.20)	1.23 (0.55)	6.61 (2.95)
	44	4.21 (1.88)	0.45 (0.20)	0 (0)	4.66 (2.08)	4.91 (2.19)	0 (0)	0.34 (0.15)	5.24 (2.34)	5.45 (2.43)	0.47 (0.21)	1.97 (0.88)	7.89 (3.52)
4A	28	4.19 (1.87)	4.32 (1.93)	3.27 (1.46)	11.80 (5.26)	5.09 (2.27)	6.50 (2.90)	2.96 (1.32)	14.50 (6.49)	5.78 (2.58)	2.82 (1.26)	3.79 (1.69)	12.40 (5.53)
	34	4.44 (1.98)	3.32 (1.48)	2.26 (1.01)	10.00 (4.47)	4.80 (2.14)	3.81 (1.70)	3.09 (1.38)	11.70 (5.22)	4.86 (2.17)	3.02 (1.35)	2.91 (1.30)	10.80 (4.82)
	35	4.12 (1.84)	3.29 (1.47)	2.46 (1.10)	9.88 (4.41)	4.46 (1.99)	4.32 (1.93)	3.61 (1.61)	12.40 (5.53)	5.00 (2.23)	3.20 (1.43)	3.23 (1.44)	11.40 (5.10)
	48	4.01 (1.79)	2.82 (1.26)	2.44 (1.09)	9.28 (4.14)	4.58 (2.04)	3.05 (1.36)	2.67 (1.19)	10.30 (4.59)	5.16 (2.30)	2.69 (1.20)	3.86 (1.72)	11.70 (5.22)
6A	33	4.15 (1.85)	2.89 (1.29)	2.06 (0.92)	9.10 (4.06)	5.22 (2.33)	4.15 (1.85)	3.29 (1.47)	12.70 (5.65)	5.45 (2.43)	1.01 (0.45)	3.02 (1.35)	9.48 (4.23)
	38	4.06 (1.81)	3.76 (1.68)	2.13 (0.95)	9.95 (4.44)	5.13 (2.29)	4.48 (2.00)	2.51 (1.12)	12.10 (5.41)	6.45 (2.88)	2.69 (1.20)	3.02 (1.35)	12.20 (5.43)
	41	4.37 (1.95)	2.78 (1.24)	2.53 (1.13)	9.68 (4.32)	4.57 (2.04)	4.17 (1.86)	2.56 (1.14)	11.30 (5.04)	5.96 (2.26)	2.56 (1.14)	3.68 (1.64)	11.30 (5.04)
	46	4.26 (1.90)	3.34 (1.49)	2.96 (1.32)	10.60 (4.71)	5.96 (2.66)	4.44 (1.98)	2.49 (1.11)	12.90 (5.75)	6.01 (2.68)	3.09 (1.38)	2.98 (1.33)	12.10 (5.39)
7A1	31	4.03 (1.80)	2.76 (1.23)	2.24 (1.00)	9.03 (4.03)	5.18 (2.31)	3.32 (1.48)	1.70 (0.76)	10.20 (4.55)	7.10 (3.17)	3.52 (1.57)	3.05 (1.36)	13.70 (6.10)
	32	3.81 (1.70)	2.73 (1.22)	2.26 (1.01)	8.81 (3.93)	4.41 (1.97)	3.90 (1.74)	1.28 (0.57)	9.59 (4.28)	6.66 (2.97)	2.87 (1.28)	2.78 (1.24)	12.30 (5.49)
	43	4.73 (2.11)	3.18 (1.42)	1.70 (0.76)	9.62 (4.29)	4.84 (2.16)	4.10 (1.83)	2.76 (1.23)	11.70 (5.22)	5.83 (2.60)	2.58 (1.15)	3.12 (1.39)	11.50 (5.14)
	45	4.06 (1.81)	3.34 (1.49)	2.31 (1.03)	9.70 (4.33)	6.30 (2.81)	4.42 (1.97)	2.51 (1.12)	13.20 (5.90)	7.24 (3.23)	3.70 (1.65)	3.25 (1.45)	14.20 (6.33)
7A2	27	4.10 (1.83)	2.76 (1.23)	3.23 (1.44)	10.10 (4.50)	5.67 (2.53)	4.24 (1.89)	2.64 (1.18)	12.60 (5.60)	5.56 (2.48)	2.11 (0.94)	4.42 (1.97)	12.10 (5.39)
	30	3.99 (1.78)	2.94 (1.31)	2.42 (1.08)	9.35 (4.17)	4.26 (1.90)	4.30 (1.92)	2.42 (1.08)	11.00 (4.90)	7.04 (3.14)	3.02 (1.35)	2.98 (1.33)	13.00 (5.82)
	39	3.99 (1.78)	2.33 (1.04)	1.88 (0.84)	8.20 (3.66)	4.82 (2.15)	3.43 (1.53)	2.62 (1.17)	10.90 (4.85)	6.03 (2.69)	1.93 (0.86)	3.54 (1.58)	11.50 (5.13)
	47	4.39 (1.96)	2.87 (1.28)	1.03 (0.46)	8.29 (3.70)	5.56 (2.48)	2.94 (1.31)	2.51 (1.12)	11.00 (4.91)	6.30 (2.81)	2.20 (0.98)	3.56 (1.59)	12.00 (5.38)
8A	25	4.17 (1.86)	2.64 (1.18)	0 (0)	6.81 (3.04)	5.60 (2.50)	3.00 (1.34)	0.52 (0.23)	9.12 (4.07)	5.69 (2.54)	1.68 (0.75)	2.22 (0.99)	9.59 (4.28)
	26	4.19 (1.87)	3.47 (1.55)	0 (0)	7.66 (3.42)	4.57 (2.04)	3.16 (1.41)	1.55 (0.69)	9.28 (4.14)	5.78 (2.58)	1.79 (0.80)	2.29 (1.02)	9.86 (4.40)
	37	4.08 (1.82)	2.44 (1.09)	0 (0)	6.52 (2.91)	4.77 (2.13)	2.78 (1.24)	0.85 (0.38)	8.40 (3.75)	5.62 (2.51)	1.97 (0.88)	2.33 (1.04)	9.93 (4.43)
	42	4.66 (2.08)	3.54 (1.58)	0 (0)	8.20 (3.66)	4.53 (2.02)	2.98 (1.33)	0.90 (0.40)	8.40 (3.75)	5.67 (2.53)	2.42 (1.08)	3.34 (1.49)	11.40 (5.10)

*Yields are expressed in terms of dry matter.

APPENDIX D

DATES AND AMOUNTS OF IRRIGATION AND RAINFALL

Table D1. Dates and Amounts of Irrigation and Rainfall.

MAY 1973											
		Irrigation									
Date	Rain-fall	2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1	1.17										
2	0.30										
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15		2.54		2.54	2.54		2.54				2.54
16			2.54			2.54		2.54	2.54	2.54	
17											
18											
19											
20											
21											
22											
23											
24	0.71										
25	0.46										
26											
27	1.02										
28	0.51										
29											
30											
31											
Total	4.17	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54

JUNE 1973											
		Irrigation									
Date	Rain-fall	2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2											
3	0.89										
4											
5	0.36										
6											
7											
8											
9											
10											
11	1.04										
12											
13		2.03		2.03			2.03				
14											
15											
16			2.80					2.80		2.80	
17											
18	1.17										
19											
20											
21		2.54	2.54		2.54	2.54			2.54	2.54	
22				2.54							
23											
24											
25			2.54		2.54			2.54		2.54	
26											
27											
28					2.54	2.54			2.54	2.54	
29		2.54	2.54								
30											
Total	3.46	7.11	10.42	4.57	7.62	5.08	2.03	5.34	5.08	10.42	

JULY 1973											
		Irrigation									
Date	Rain-fall	2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2											
3	2.90										
4		2.54		2.54	2.54		2.54				2.54
5			2.54			2.54		2.54	2.54	2.54	
6											
7											
8											
9	2.08		2.54	2.54		2.54		2.54			2.54
10											
11											
12				2.54		2.54			2.54		2.54
13			2.54								
14											
15											
16											
17											
18		2.54			2.54		2.54				2.54
19											
20		2.54	2.54	3.38			2.54	2.54	2.54		2.54
21											
22	0.23										
23	0.68		2.54		2.54		2.54		2.54		2.54
24	0.23										
25											
26											
27		2.54			2.54	2.54		2.54			2.54
28											
29											
30		2.54	2.54	2.54			2.54	2.54			
31											
Total	6.12	12.70	15.24	13.54	10.16	10.16	12.70	12.70	10.16	2.54	17.78

AUGUST 1973											
		Irrigation									
Date	Rain-fall	2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2				3.38		2.54			2.54		3.38
3	0.48										
4			2.54					2.54			
5		3.38			3.38		3.38				
6											
7	0.71										
8	0.38		2.54	2.54		2.54			2.54		
9											
10											
11						2.54		2.54			2.54
12											
13		2.54	2.54		2.54						
14											
15	0.30								2.54		2.54
16							2.54				
17		2.54	2.54	2.54							
18								2.54			
19											
20					2.54	2.54					2.54
21											
22		2.54	2.54						2.54		
23					2.54		2.54				
24											
25								2.54			
26											
27		2.54	2.54	2.54		2.54					2.54
28											
29											
30				2.54			2.54				
31											
Total	1.87	13.54	15.24	13.54	11.0	12.70	11.00	10.16	10.16	0.00	13.54

Table D1. Dates and Amounts of Irrigation and Rainfall (continued).

SEPTEMBER 1973

Date	Rain-fall	Irrigation 2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2											
3	1.42										
4					2.54		2.54				2.54
5											
6											
7											
8											
9											
10		2.54	2.54		2.54	2.54	2.54	2.54	2.54	2.54	
11											
12				2.54							
13											
14					2.54		2.54				2.54
15	1.07										
16											
17	0.46										
18											
19											
20	0.20										
21											
22											
23											
24											
25	0.51										
26	2.08										
27	0.66										
28											
29	0.30										
30											
Total	6.70	2.54	2.54	2.54	7.62	2.54	7.62	2.54	2.54	2.54	5.08

MAY 1974

Date	Rain-fall	Irrigation 2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2											
3											
4											
5											
6											
7											
8	0.33										
9											
10											
11	2.16										
12											
13	1.35										
14											
15											
16	0.74										
17											
18	1.40										
19											
20											
21	2.13										
22											
23											
24											
25											
26											
27	0.33										
28	0.23										
29											
30	1.29										
31	0.84										
Total	10.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

JUNE 1974

Date	Rain-fall	Irrigation 2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2											
3											
4											
5											
6	0.43										
7	0.25										
8											
9	2.46										
10	0.15										
11											
12											
13											
14											
15											
16											
17											
18			5.08			5.08		5.08	5.08	5.08	
19											
20											
21	0.30										
22			2.54			2.54		2.54	2.54	2.54	
23											
24											
25											
26		2.54		2.54	2.54		2.54				2.54
27											
28		2.54	5.08	2.54	2.54	2.54	2.54	5.08	5.08	5.08	2.54
29											
30											
Total	3.59	5.08	12.70	5.08	5.08	10.16	5.08	12.70	12.70	12.70	5.08

JULY 1974

Date	Rain-fall	Irrigation 2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1						2.54					
2											
3	0.79	2.54	2.54		2.54		2.54	2.54			
4											
5											
6											
7											
8		2.54	2.54	2.54		2.54			2.54		2.54
9	0.79										
10					2.54		2.54		2.54		
11											
12			2.54	2.54				2.54			2.54
13											
14	1.30										
15		2.54			2.54	2.54					2.54
16											
17						2.54		2.54			
18	0.56										
19	0.41	2.54	2.54	2.54					2.54		
20	0.69										
21											
22					2.54		2.54				2.54
23											
24		2.54				2.54		2.54			
25											
26			2.54	2.54					2.54		2.54
27											
28											
29		2.54			2.54		2.54		2.54		2.54
30											
31							2.54		2.54		
Total	4.54	15.24	12.70	10.16	12.70	12.70	12.70	10.16	15.24	0.00	15.24

Table D1. Dates and Amounts of Irrigation and Rainfall (continued).

AUGUST 1974

		Irrigation									
Date	Rain- fall	2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2	0.46	2.54	2.54	2.54							2.54
3											
4											
5					2.54	2.54		2.54			2.54
6											
7		2.54	2.54				2.54	2.54			
8	3.81										
9	2.39										
10											
11											
12											
13											
14		2.54	2.54	2.54			2.54	2.54			2.54
15											
16	0.68										
17											
18											
19		2.54	2.54		2.54	2.54			2.54		2.54
20											
21	0.25				2.54	2.54			2.54		
22											
23											
24											
25											
26			2.54	2.54			2.54				2.54
27											
28		2.54		2.54			2.54	2.54			
29											
30					2.54	2.54		2.54	2.54		
31											
Total	7.59	12.70	12.70	10.16	10.16	10.16	10.16	12.70	7.62	0.00	12.70

SEPTEMBER 1974

		Irrigation									
Date	Rain- fall	2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2		2.54	2.54		2.54	2.54			2.54		
3											
4											
5											
6					2.54		2.54				
7											
8											
9		2.54		2.54			2.54				2.54
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											
22											
23											
24											
25											
26											
27											
28											
29											
30											
Total	0.00	5.08	2.54	2.54	5.08	2.54	5.08	0.00	2.54	0.00	2.54

MAY 1975

		Irrigation									
Date	Rain- fall	2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2											
3	0.15										
4											
5											
6											
7	1.02										
8											
9											
10											
11	0.66										
12											
13											
14	0.25										
15											
16											
17											
18											
19											
20											
21											
22											
23	0.89										
24											
25											
26											
27											
28											
29											
30											
31											
Total	2.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

JUNE 1975

		Irrigation									
Date	Rain- fall	2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2											
3	0.18										
4	0.48		1.27			1.27		1.27	1.27	1.27	
5			3.18			3.18		3.18	3.18	3.18	
6											
7											
8											
9	3.53										
10											
11	0.15										
12	0.61										
13											
14											
15	1.35										
16	0.94										
17											
18											
19	0.96										
20	1.60										
21	0.36										
22	0.28										
23											
24											
25											
26											
27											
28											
29											
30											
Total	10.44	0.00	4.45	0.00	0.00	4.45	0.00	4.45	4.45	4.45	0.00

Table D1. Dates and Amounts of Irrigation and Rainfall (continued).

JULY 1975		Irrigation									
Date	Rain-fall	2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2											
3			2.54			2.54		2.54	2.54	2.54	
4											
5											
6	0.25										
7		2.54	2.54	2.54	2.54		2.54	2.54		2.54	2.54
8											
9											
10											
11		2.54	2.54	2.54		2.54		2.54	2.54	2.54	2.54
12											
13											
14											
15		2.54	2.54		2.54		2.54		2.54		2.54
16											
17											
18											
19		2.54	2.54	2.54		2.54		2.54			2.54
20											
21											
22	0.15										
23	1.68										
24	0.18										
25		2.54	2.54		2.54		2.54		2.54		2.54
26											
27											
28											
29											
30											
31											
Total	2.26	12.70	15.24	7.62	7.62	7.62	7.62	10.16	10.16	7.62	12.70

AUGUST 1975		Irrigation									
Date	Rain-fall	2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1	5.21	2.54	2.54	2.54		2.54		2.54			2.54
2	0.20										
3											
4			2.54		2.54		2.54		2.54		2.54
5											
6											
7											
8		2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54		2.54
9		2.54	2.54	2.54		2.54		2.54			2.54
10											
11	0.35										
12	1.14										
13					2.54		2.54		2.54		
14											
15		2.54	2.54	2.54		2.54		2.54			2.54
16											
17											
18	0.30										
19	3.71										
20					2.54		2.54		2.54		
21	0.33										
22	0.64										
23											
24											
25						2.54		2.54			
26											
27											
28	1.47										
29											
30	0.18										
31											
Total	13.50	10.16	12.70	10.16	10.16	12.70	10.16	12.70	10.16	0.00	12.70

SEPTEMBER 1975		Irrigation									
Date	Rain-fall	2C	4A	5C1	5C2	6A	6C	7A1	7A2	8A	8C
1											
2		2.54	2.54	2.54	2.54		2.54		2.54		2.54
3											
4											
5	0.96										
6											
7											
8											
9											
10											
11	5.36										
12											
13											
14											
15											
16											
17											
18	1.90										
19											
20	0.20										
21											
22											
23											
24											
25											
26											
27											
28	1.37										
29	0.25										
30											
Total	10.00	2.54	2.54	2.54	2.54	0.00	2.54	0.00	2.54	0.00	2.54

APPENDIX E

COMPARISON OF ANNUAL FIXED COSTS USING STEGMAN'S (1975) DATA

Table E1. Comparison of Annual Fixed Costs for Multiple Field Use of a Center Pivot Using Stegman's 1975 Data.

Management scheme	Seasonal irrigation depth+ cm (in)	Number of moves+	Estimated electrical costs, $ Total	Estimated electrical costs, $ $/ha ($/acre)	Annual fixed costs $/ha ($/acre)	Additional labor costs $/ha ($/acre)	Total costs° $/ha ($/acre)	Difference in costs from 1 center pivot on 1 field $/ha ($/acre)
Corn 1 center pivot on 1 field	23 (9)	0	1520	28.90 (11.70)	163.10 (66)	0	192.00 (77.70)	0 (0)
Corn 1 center pivot on 2 fields	53 (21)	7	2720	25.90 (10.50)	113.70 (46)	2.20 (0.90)	141.80 (57.40)	50.20 (20.30)
Corn 1 center pivot on 3 fields	84 (33)	10	4090	25.90 (10.50)	96.40 (39)	2.00 (0.80)	124.30 (50.30)	67.70 (27.40)
Alfalfa 1 center pivot on 1 field	30 (12)	0	1770	33.60 (13.60)	163.10 (66)	0	196.70 (79.60)	0 (0)
Alfalfa 1 center pivot on 2 fields	66 (26)	8	3150	29.90 (12.10)	113.70 (46)	2.50 (1.00)	146.10 (59.10)	50.60 (20.50)
Alfalfa 1 center pivot on 3 fields	99 (39)	10	4630	29.40 (11.90)	96.40 (39)	2.00 (0.80)	127.80 (51.70)	68.90 (27.90)

*The procedure and the price assumptions are the same as presented in the text.
+Data from Stegman's (1975) work.
°Total costs are electrical costs plus annual fixed costs plus additional labor costs. Note that the costs do not include production costs.